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Campus Re-engineered: Tackling problems close to home to promote interest in the field of Materials Science and Engineering for non-majors

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Abstract:

Everyone is a materials scientist. We all use materials in different ways in our day-to-day lives, so we each have a unique intuition that guides us when we approach materials selection challenges. However, students may not immediately realize the relevance of Materials Science and Engineering (MSE) to their own lives – especially non-MSE engineering majors. As a result, one of the ever-present challenges in teaching a required introductory MSE course to a broad engineering audience is creating student buy-in. We posit that this barrier can be overcome by situating materials selection within the context of a college campus. In this study, we implement a final project in an undergraduate Intro to Materials Science course which requires students to weave together technical knowledge from the course with their own life experience to solve a problem on campus. Through a student survey, we seek to understand the sources of knowledge students leverage in order to identify and address an on-campus materials-related challenge. We further explore the impact of this project and the MSE course as a whole on students' attitudes towards the following: sense of belonging in MSE, relevance of MSE to the student's major, and relevance of MSE in addressing challenges in students' communities.

Introduction:

Materials science and engineering (MSE) is a highly interdisciplinary field that draws from chemistry, physics, biology, mathematics, and the arts to understand the relationship between the structure of matter and its properties and applies these structure-property relationships to design new materials. The interdisciplinary nature of MSE not only provides an opportunity to engage students from a wide variety of STEM majors, but also to engage students based on their unique life experiences. Each person interacts with materials on an everyday basis, meaning that each student already has unique pre-existing knowledge about how materials behave. From cooking, to skincare and makeup, to car maintenance, we all have hands-on life experience with countless materials that guides us towards an understanding of structure-property relationships.

In this work, we implement a final project in an introductory MSE course in which students are asked to 1) identify an area of opportunity or "problem" on campus, 2) propose a materials-enabled solution to the problem, and 3) present a poster that outlines the proposed on-campus project. By setting the project on-campus, students are being asked to draw from their own life experience and think about issues that impact themselves and other members of the campus community. This final project was selected for several reasons. First, it is designed to encourage students to tap into their *funds of knowledge*, or their unique perspectives imparted by family, community, and peers [1]. The funds of knowledge framework, which was originally developed by Vélez-Ibáñez and Greenberg in 1992 in Tucson, Arizona [2], [3], views students' prior knowledge and life experiences as an asset that augments student learning [4] rather than expecting students to adapt to a way of thinking imparted by the course or college environment [5]. The implementation of asset-based frameworks in STEM courses at the K-12 and post-secondary level aims to "change the ways of knowing that are valued within engineering." [6] Second, research suggests that women, students from groups historically underrepresented in STEM, and first-generation college students are more drawn to fields that they perceive as altruistic and can lead to careers in which they can help others [7], [8], [9], [10], [11], [12], [13]. Therefore, by using this project to situate MSE as a field in which students could impact their communities, we hope to increase interest in MSE. Finally, there is evidence to support that campus-related projects improve student outcomes by providing real-world experience [14], [15], [16], and can also provide a benefit to the university [17].

In this work, we seek to understand the impacts of a campus-focused design project on students' 1) sense of belonging in the field of MSE, 2) sense of relevance of MSE to their area of study, and 3) understanding of the applicability of MSE to address societal challenges. We further seek to understand whether students who reported that they drew from their own background knowledge to complete this project were more likely to report that the project and the course contributed to their sense of belonging in the field of MSE.

Methods:

This study was conducted at Stevens Institute of Technology, which has an enrollment of about 4,000 undergraduate students. The engineering program at this institution does not offer a Materials Science and Engineering major, but every engineering major is required to take an introductory MSE course as part of their core requirements. Therefore, the ~320-person introductory MSE course in which this study took place consisted of mostly 3rd year college students from a wide variety of engineering-related majors (Table 1). The topics covered in the course included: chemical bonding, structure and properties of polymers, crystal structure of metals, defects in metals, structure and properties of ceramics, diffusion in materials, mechanical properties of materials, composite materials, materials processing, electrical properties of materials, optical properties of materials, and nanomaterials.

Table 1: Student majors in the course.

Major	**Percent of class**
Mechanical Engineering	41%
Computer Engineering	14%
Electrical Engineering	11%
Chemical Engineering	10%
Software Engineering	9%
Engineering Management	6%
Unknown	6%
Civil Engineering	2%
Environmental Engineering	1%

Table 2 outlines the structure of the four-credit, 15-week MSE course. The course consisted of three parts: Lecture, Lab, and Design. The purpose of the recitation-style Design sections was for students to work on design projects that allowed them to explore materials selection problems.

Table 2: Structure of MSE course.

	Lecture	**Lab**	**Design**
Frequency	2x/week	1x/week	1x/week
Duration	50 min	1 hr 50 min	1 hr
Format	Large-group, led by Professor	12-person sections, led by graduate student teaching assistant	12- to 24-person sections, led by undergraduate Design facilitator who had previously taken the course

In weeks 8-15 of the course, students worked on a project during the Design sections called Campus Re-Engineered. The goal of the project was for students to identify a problem on campus and to propose a materials-enabled solution to the problem. In this project, we defined the term *materials-enabled* as follows:

> *Materials-enabled means that a particular outcome is made possible through selection and engineering of materials. For our purposes, we will define the solution to a problem to be materials-enabled if consideration of materials properties or processing plays a significant role in the development of the proposal.*

We asked students to focus their projects on campus-related problems, rather than expand to problems that face the surrounding community, to limit the scope of the project in its first iteration.

Students worked on these projects in groups of three, and the project culminated in a public poster session on campus during the final day of class. Students were given the option to choose their groups. Given the open-ended nature of the project, students worked closely with their Design facilitators to ensure that their project topics were related to materials science, and to hone their proposed solutions. Table 3 depicts the timeline of the project.

Table 3: Project timeline.

Week Number	**Design activity**	**Project component due at beginning of class**	**Role of Design Facilitator**
8	*Brainstorming:* First, to prime students to think about materials in their lives, groups were asked to identify situations that required them to use their intuition about materials properties in day-to-day life. Then, groups wrote down as many on-campus problems as	None	Introduced project, assisted students in brainstorming; facilitated class discussion after brainstorming.

	possible, and brainstormed materials-based solutions to these problems. The class created a list of possible project topics.		
9	*Writing a project proposal:* Groups came to class with two project ideas and worked with their facilitator to choose one idea.	Describe two possible project ideas in a short paragraph	Checked in with each group about both of their project ideas; helped them decide on one.
10	*How to create a research poster:* Discussion of best practices for making posters on PowerPoint. Students critiqued posters exhibited around the academic buildings.	Project proposal (~1 page)	Presented slides on how to make an effective poster; assisted groups in setting up their posters in PowerPoint.
11	*Project/poster work time:* Facilitators checked in with each group, answered questions, and redirected any groups whose projects were veering away from materials science.	None	Walked around the room to check in on each group and answer questions.
12	No class (Thanksgiving)	None	
13	*Poster feedback:* Each group presented their poster draft and the class and facilitator provided feedback.	Submit poster draft	Facilitated student presentations; facilitated student critiques; offered feedback.
14	*Practice poster presentations:* Each group presented their final poster and practiced giving a 3-5 minute overview of their work, with questions from the rest of the class.	Submit final poster	Facilitated student presentations and Q&A
15	Poster Session (during lecture sections)	None	Took attendance during poster session

This project produced 110 posters, which students presented at a poster session during Week 15 (the week before final exams). The posters were evaluated based on the scoring rubric in Table 4, which was made available to students at the start of the project.

Table 4: Poster grading rubric.

Criteria	Points possible
Format: Poster contains title and authors/affiliations, the layout of the poster makes sense, poster has a balance of text and images, no large blocks of dense text, no part of the format detracts from the interpretation of the poster, all text is an appropriate size, a few key references are included	4
Area of opportunity: The area of opportunity (problem) and its significance is clearly explained.	2
Materials-enabled solution: The proposed solution to the problem is clearly explained. It is clear how materials selection and/or processing played a role in the development of the solution.	3
Structure-property relationships: The relationship between the structure of relevant materials and properties is made clear. For all materials properties that are discussed, it is clear WHY these properties are relevant.	3
Cost to the university is estimated and included on the poster.	2
The poster overall makes a strong pitch for the proposed project.	1

A survey was administered in the Design sections in Week 14 of the course with IRB approval and consisted of two sections. In Part I of the survey, students were asked to rate the extent to which they relied on the following during their completion of this project: a) their own prior knowledge of properties and behaviors of materials, b) knowledge they gained from the course (lectures, readings labs, etc.), and c) their own research that they conducted for this project to find new information outside of what they already knew or learned in class. Students rated their response on a 4-point Likert scale from “Not at all” to “A significant amount”. In Part II of the survey, students were asked to rate the following statements regarding the impacts of the course as a whole and the Campus Re-Engineered project on their impressions of the field of MSE, on a 5-point Likert scale from “Strongly Disagree” to “Strongly Agree.”

> *This course as a whole has positively impacted my sense of belonging in the field of materials science and engineering (MSE).*
>
> *This project specifically has positively impacted my sense of belonging in the field of MSE.*
>
> *This course as a whole has shown me the relevance of MSE to my field of engineering.*
>
> *This project specifically has shown me the relevance of MSE to my field of engineering.*
>
> *This course as a whole has shown me the role that MSE can play in addressing problems that impact my community.*
>
> *This project specifically has shown me the role that MSE can play in addressing problems that impact my community.*

We chose these constructs as indicators for student attitudes towards MSE rather than asking students to rate their interest in continuing in the field of MSE due to the lack of opportunities for undergraduates at this institution for continuing study in MSE. The survey was taken by 102 students, resulting in a 31% response rate.

Results and discussion:

The Campus Re-Engineered project was carried out during weeks 8-15 of the course, as indicated in Table 3. Here, we discuss in detail a few of the pivotal activities that were carried out during Design as students worked towards their final projects.

In order to create an emphasis on students' prior experience with materials in everyday life, the Week 8 Design sections began with a warm-up in which students were asked to brainstorm a few examples of situations in which they needed to use their intuition about material properties to make a decision. Students were provided with a few examples, such as wearing waterproof shoes in the rain, or deciding what type of container to microwave something in. The purpose of this activity was to start a discussion about how students' prior intuition about materials selection could be taken into consideration when approaching the Campus Re-Engineered project. Table 5 shows some student responses to this brainstorming activity. Responses have been edited for clarity. We observe that in completing this exercise, some students considered daily activities (e.g., cooking and washing clothes), while others considered products that they use everyday (e.g., glasses and sports equipment) and the considerations that may have gone into materials selection for those products.

Table 5: Examples of student responses to a 10-minute warmup that asked students to brainstorm everyday materials decisions that they make.

Student Responses
When cooking with nonstick pan, use plastic/wood utensils to not ruin the nonstick layer
Washability of clothing/coats – cottons are more resilient
Anti-fogging materials are used to prevent fogging on goggles and glasses
Pickleball paddle – uses material with high energy return on hits

Following this activity, students were asked to come up with a list of problems on campus, without regard to whether those problems could be solved by materials science and engineering. Then, students were asked to brainstorm materials-enabled solutions for as many of those problems as possible. Table 6 lists some examples of problems and solutions that students generated. Names of specific buildings or locations on campus have been replaced with generic descriptors. Dashes are present in the Materials-Enabled Solution column for problems for which students did not come up with a materials-related solution.

Across sections, students generated a wide-ranging list of problems that encompassed safety issues, systemic inequalities on campus, campus aesthetics, and inconveniences. At this stage, students were encouraged to freely brainstorm solutions to these problems without regard for how possible the implementation would be, resulting in a few over-the-top or humorous suggestions (e.g., alpaca chairs). Anecdotally, Design facilitators noticed that providing students with the opportunity to discuss issues they faced on campus and to be as creative as possible in identifying solutions allowed for moments of humor and community-building during class.

Table 6: Examples of student responses to brainstorming on-campus problems and materials-enabled solutions.

Problem	**Materials-Enabled Solution**
Bolts keep snapping in the gym on the rowing machine	Utilize a different material with higher impact and tensile strength
Flooded roads	Permeable concrete
Snake in the building	-
Cold food in dining hall	More insulated food storage material
Library entrance doors are too heavy	Make frame out of lighter material/put more lubricant on the hinges
Need better chairs in classrooms	Alpaca chairs
Lanternfly infestation on outside of buildings	Coat buildings with an anti-glare/matte coating to reduce attraction from lantern flies
Paint easily comes off in the living spaces	Implement a paint solution that is more resistant to sheer load
Lobby is so hot always	Tinting material on glass windows
No more clean your own dishes in dining hall	Choose a material for the plates that is more non-stick so they don't have to rely on the students to clean their own plates
Wheelchair accessibility	-
Plastic utensils in dining hall	Use bamboo
Unable to deadlift in gym due to noise	Energy-absorbing pads or flooring by racks that disperse force and dampen noise
Few spaces for commuters	-
Dining hall food sucks	Add more salt

Over the next couple of weeks, students solidified their project ideas with input from their Design facilitator. Some example project titles included: "Bio-Degradable Utensils in Dining Services," "Re-Mark-Able Whiteboards," "Floorward Thinking: Revolutionizing Slip Resistance," "Rust-free Reps: A Corrosion-Resistant Coating for Barbells," "Bye-Bye Lanternfly," and "In Contact with Copper: Antimicrobial Engineering Solutions for High-Contact Surfaces." Figure 1 displays the breakdown of topics that were chosen for the project by campus location or issue (Figure 1a) and by material property (Figure 1b). Gymnasiums and windows were popular project topics, and 45% of posters predominantly focused on mechanical properties of materials. Sustainability is included as a category in Figure 1b to indicate that some projects placed a greater importance on the sustainability of the material rather than the performance of the material. It is possible that the large number of posters related to mechanical properties is correlated with the fact that mechanical engineering was the most-represented major in the course (Table 1).

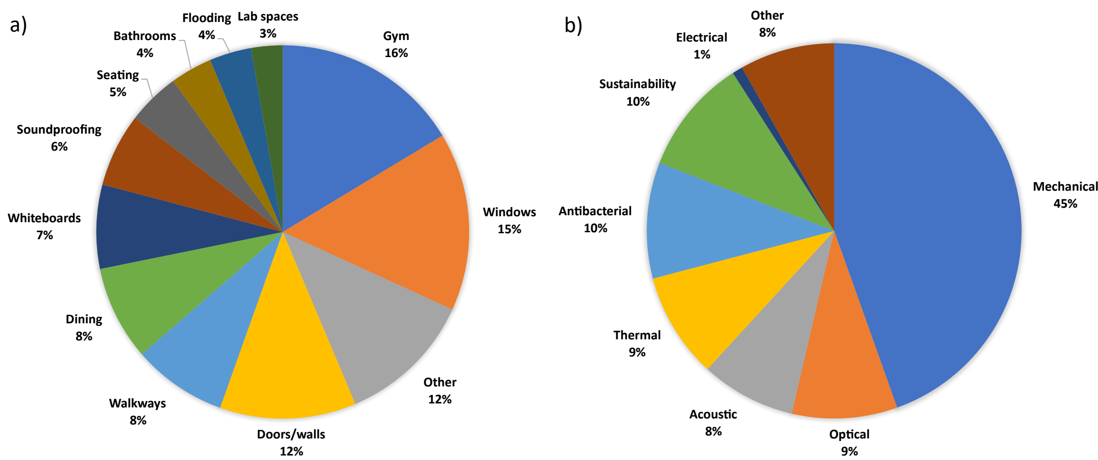

Figure 1: a) Student posters categorized by campus location or issue. b) Student posters categorized by material property (N=110).

During Week 14 of the course, students were asked to complete a survey regarding their experience with the Campus Re-Engineered project. First, students were asked to indicate the extent to which they relied on the following during their completion of this project: a) their own prior knowledge of properties and behaviors of materials, b) knowledge they gained from the course (lectures, readings labs, etc.), and c) their own research that they conducted for this project to find new information outside of what they already knew or learned in class.

Figure 2 displays the extent to which students self-reported their reliance on each source of knowledge. A majority of respondents indicated that they relied on knowledge from their own research and the course to a significant or moderate extent (80% and 91% of respondents, respectively). However, respondents were split on the extent to which they relied on their own prior knowledge of the properties and behavior of materials. Fifty-four percent of respondents indicated that they did not rely on their prior knowledge or relied upon it to a small extent, while 46% of respondents indicated that they relied on their own prior knowledge to a moderate or significant extent.

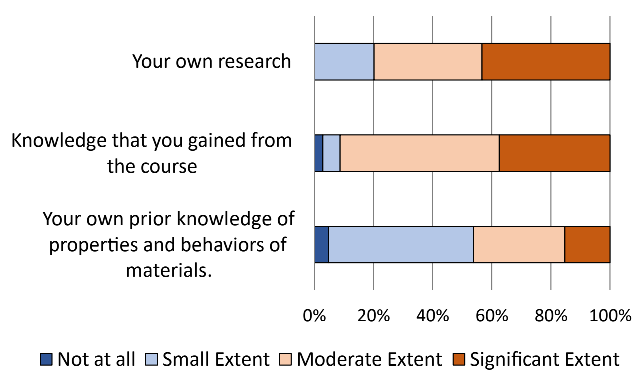

Figure 2: Student perceptions of the extent to which they relied on three different sources of knowledge for the Campus Re-Engineered project. (N=102).

Figure 3 displays the results for each of the six statements in Part II of the survey regarding students' attitudes towards the course as a whole and the Campus Re-Engineered project. Students were generally positive towards both the course and the project as being factors that impacted each of the three constructs: addressing problems that impact my community, relevance of MSE to my field of engineering, and sense of belonging in the field of MSE. For each construct, students rated the course as having a similar or greater impact than the project specifically. This difference is especially apparent for sense of belonging: while 82% of students agreed that the course as a whole positively impacted their sense of belonging in MSE, only 62% of students reported the same for the project.

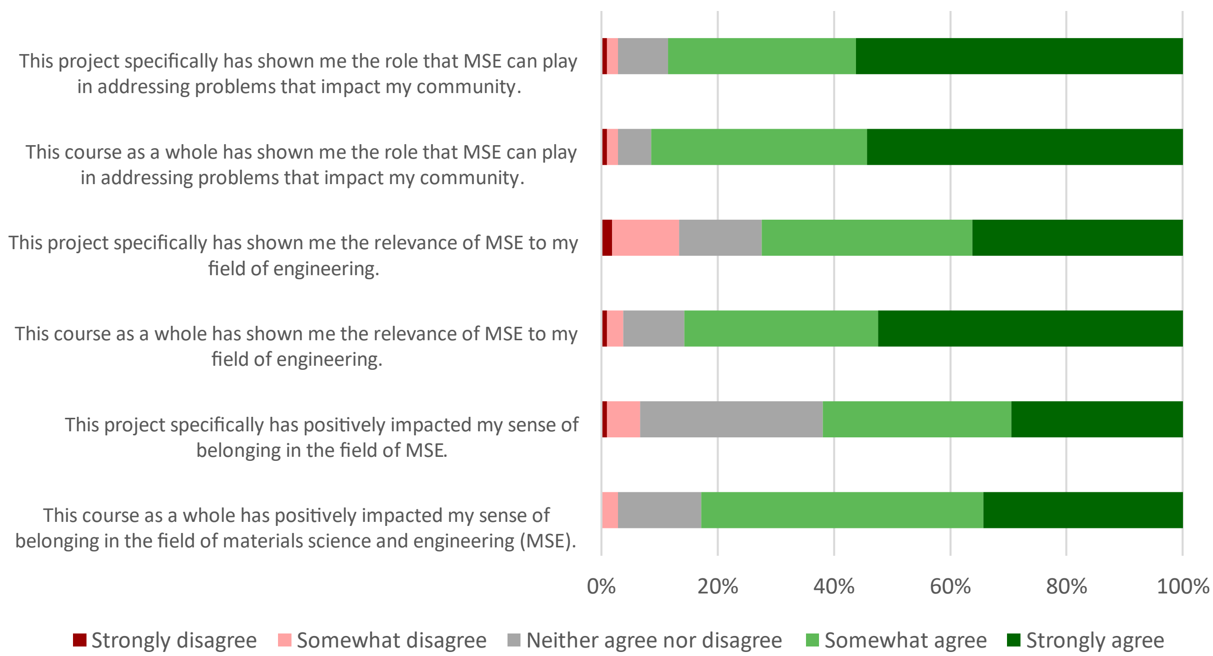

Figure 3: Student attitudes towards each of three constructs with respect to the course as a whole and the Campus Re-Engineered project.

In Part I of the survey, we noted a near-even split between students who did and did not consider their prior knowledge to be at least moderately helpful for this project (Figure 2), as measured by the following survey question:

> *In completing this project, to what extent did you rely on your own prior knowledge of properties and behaviors of materials.*

Due to the apparent divide, we questioned whether there might be a relationship between students' reliance on prior knowledge and any of the remaining six questions in Part II of the survey (Figure 3). Accordingly, Figure 4 compares data for each of the six questions based on whether students self-reported their reliance on prior knowledge as small or none (N=55), versus significant or moderate (N=46).

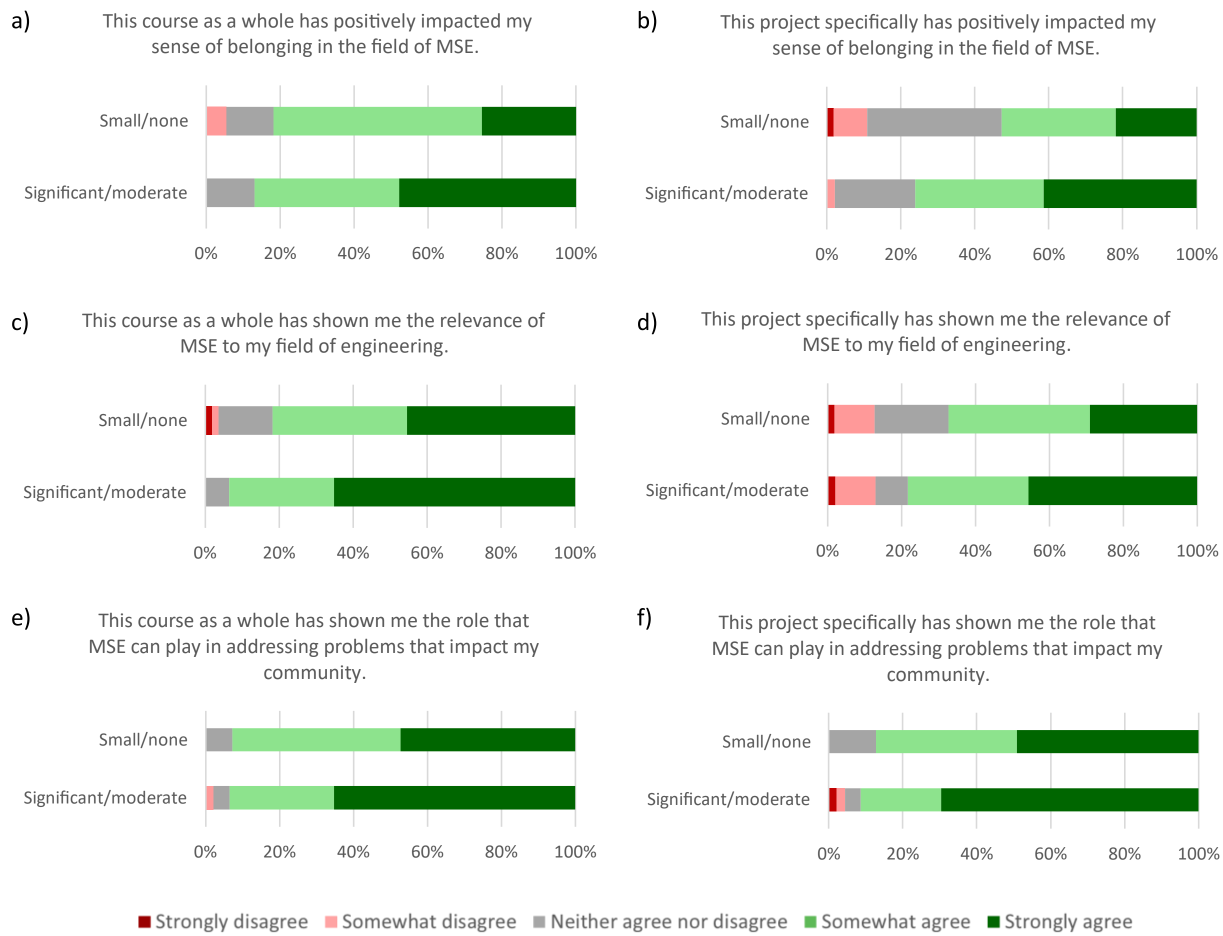

Figure 4: Responses to each of the six questions in Part II of the survey. Students are separated according to the extent to which they reported their reliance on prior knowledge in completing the project (i.e., to a small or no extent vs. a significant or moderate extent).

A Mann-Whitney *U* test was then performed on each of the six survey items in Part II to identify any significant differences between the two groups of students: small/none and significant/moderate (Table 7). The Mann-Whitney *U* test – sometimes referred to as the Wilcoxen rank-sum test – is the non-parametric version of the independent t-test and is commonly used to identify significant differences between two unrelated groups with ordinal (ranked) data, such as that which results from Likert scale surveys. The effect size r can then be calculated for any significant differences found using the equation $r = \frac{z}{\sqrt{N}}$. Our findings in Table 7 suggest that there was a significant difference between the two groups for both questions pertaining to the sense of belonging construct, with low-moderate effect size.

Table 7. Student responses to the six survey items in Part II based on the extent of their reliance on prior knowledge, as measured in Part I. Student responses are numbered 1-5, whereby 1 corresponds to Strongly Disagree and 5 corresponds to Strongly Agree, and are listed as a percentage. Z-scores from the Mann-Whitney *U* test are provided and an asterisk (*) indicates significance at the p≤0.05 level. Effect sizes were calculated by dividing the z-score by the square root of the total sample size (N=101).

Survey Item - Attitudes	Reliance on Prior Knowledge	Student Response (%)					z-score	Effect size, *r*
		1	2	3	4	5		
This course as a whole has positively impacted my sense of belonging in the field of MSE.	Significant/ Moderate	0.0	0.0	13.0	39.1	47.8	-1.97*	0.19
	Small/None	0.0	5.5	12.7	56.4	25.5		
This project specifically has positively impacted my sense of belonging in the field of MSE.	Significant/ Moderate	0.0	2.2	21.7	34.8	41.3	-2.60*	0.26
	Small/None	1.8	9.1	36.4	30.9	21.8		
This course as a whole has shown me the relevance of MSE to my field of engineering.	Significant/ Moderate	0.0	0.0	6.5	28.3	65.2	-1.96	N/A
	Small/None	1.8	1.8	14.5	36.4	45.5		
This project specifically has shown me the relevance of MSE to my field of engineering.	Significant/ Moderate	2.2	10.9	8.7	32.6	45.7	-1.50	N/A
	Small/None	1.8	10.9	20.0	38.2	29.1		
This course as a whole has shown me the role that MSE can play in addressing problems that impact my community.	Significant/ Moderate	0.0	2.2	4.3	28.3	65.2	-1.45	N/A
	Small/None	0.0	0.0	7.3	45.5	47.3		
This project specifically has shown me the role that MSE can play in addressing problems that impact my community.	Significant/ Moderate	2.2	2.2	4.3	21.7	69.6	-1.67	N/A
	Small/None	0.0	0.0	12.7	38.2	49.1		

Overall, students tackled a relatively open-ended project with guidance from their Design facilitators over the course of eight weeks, leading up to a poster presentation. The project was broken down into week-by-week deliverables, and students were provided with ample time during their Design sections to communicate with their group and facilitators to ensure that the topic of their project was aligned with the theme of materials science and engineering. The survey results show that students expressed positive attitudes towards both the project and the overall course as they relate to sense of belonging in MSE, the role MSE can play in addressing societal challenges, and the relevance of MSE to each students' field of study.

Limitations and future work:

This work has limitations in both the implementation of the Campus Re-Engineered project, and in the analysis of student data. In terms of the project implementation, a clear limitation is that these projects are not actually carried out on campus. Students simply propose an idea without being afforded the opportunity to implement their work. The size of the course (approximately 300 students in the fall and 100 students in the spring) presents a challenge in providing funding for students to carry out their projects. Further, since some projects propose major alterations on campus, the timeline for implementation of these projects may be longer than the duration of a student's time at this institution. Perhaps in future iterations of this course, projects could be evaluated by campus staff and selected for the possibility of implementation. However, a focus on projects that would be practical to implement may dissuade students from being as creative as possible.

Another limitation of the project itself was identified by commuter students, who noted that it was challenging to formulate an idea for an issue on campus. To make this project more inclusive of commuters, we plan to open up the project to areas of opportunity on campus or in students' home communities.

A limitation of this work related to the data analysis is that terms in the survey, such as "sense of community" and "prior knowledge," were not defined for students, as we wanted the results to reflect students' own interpretation of these terms. However, the lack of a standardized definition for "prior knowledge" presents a limitation of the applicability of the funds of knowledge framework; students could interpret prior knowledge as either knowledge they acquired about materials through their own life experience, or knowledge they acquired about materials through other courses. Mechanical engineers, for example, had already been exposed to stress-strain curves in other courses before they were covered in this course. Therefore, if a student indicated that they relied heavily on their prior knowledge, it could simply mean that the student was already exposed to some of the technical content of the course. Students who are covering certain content for the second time may feel a greater sense of belonging in the field because they feel they have a greater expertise in the content. In future iterations of this study, separating these two sources of prior knowledge in the survey could help identify whether honoring students' backgrounds and life experiences contributes to a greater sense of belonging in MSE.

One final limitation for this study is that the survey we implemented did not allow for us to dig deeper into the differences between student outcomes as a result of the whole course versus the project. While we suspect that some differences do exist, particularly for students' sense of belonging (Figure 3), we are unable to confirm this is the case or extract meaning from such results. Similarly, it is plausible that individual participants differed in how they interpreted some of the terms used in our survey, such as how they define their "community" or what "belonging" means to them. These limitations may be addressed in the future by supplementing our study with a qualitative component, such as interviewing a sample of students. Likewise, in future iterations of this study, we plan to collect demographic information about students such as gender and race, as these factors have also been shown to play a role in students' sense of belonging in STEM [18], [19].

Conclusions:

In this study, we examined students in a large, mixed-major introductory MSE course following their completion of a final project in which they worked in groups to design a materials-enabled solution for a problem they identified on campus. We administered a survey to gauge the sources of knowledge students pulled from during the scope of this project (Part I), as well as the impact of the course and project on three different constructs (Part II). Analysis of Part I of the survey suggested that most students reported relying on knowledge they gained from the course or from their own research for the project to at least a moderate extent. In comparison, just under half felt similarly regarding their reliance on their own prior knowledge. In Part II of the survey, we found that the project and course appeared to positively impact students' sense of belonging and enabled them to understand the relevance of MSE to both their own field of study as well as the world around them.

Notably, there appeared to be a relationship between students' use of prior knowledge and their feelings of belonging. One possibility to explore is whether the underlying cause of this relationship is tied to the funds of knowledge framework. Perhaps the opportunity for students to utilize knowledge from their life experiences with materials helped lead to feelings of belonging in the field of MSE. However, it could also be the case that students who had encountered materials science concepts in other courses were drawing from this prior course-related knowledge.

We suggest that practitioners take deliberate steps to show students how the knowledge they bring with them from past life experiences is valuable to engineering solutions to global challenges. The survey results suggest that students generally had positive feelings towards the project. Given the successful low-cost implementation of this project in a non-major, large-format course, this type of project can easily be adapted by instructors looking to meaningfully engage students across engineering backgrounds.

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