Curriculum Design for All Learners

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Abstract: How should pre-college engineering courses evolve in response to teacher and students' needs and experiences? Curriculum development can take an engineering approach in order to meet the needs of all teachers and students.

In 2018, the project Engineering For Us All (e4usa) began efforts to develop and implement a new engineering course to engage all high school students in "doing" engineering, authentically, at an age-appropriate level. At the same time, e4usa launched professional development efforts and a supportive learning community to help interested teachers, including those without an engineering background, to implement the course with rigor. For the past three years e4usa has been soliciting feedback and examining teacher and student experiences with the goal of curricular improvement.

This paper aims to characterize evidence of the self-reported impact of the e4usa curriculum on all participating students, drawn from evaluation data collected from students (n= 846) over a period of three years from 2021 to 2023. Results will illuminate students' opinions about the curriculum and what they most / least appreciate, with patterns of responses illustrating a variety of student "personas" characterized by what they most/least value in the curriculum. The paper highlights aspects of the curriculum that are most valuable to a variety of students, and how to improve the curriculum to better serve all students.

Curriculum Design for All Learners (Evaluation)

Introduction

The United States Department of Labor projects a 10.4% increase in STEM-related employment from 2023 to 2033 [1]. However, high school students face inadequate preparation for STEM fields, and the STEM workforce is experiencing attrition. The report from the National Science Foundation (NSF) indicates that the proportion of high school students meeting college readiness benchmarks in STEM subjects declined from 19% in 2021 to 16% in 2022 [2]. Moreover, 24% of recent bachelor's degree recipients in science and engineering have opted to leave STEM fields [3]. These challenges highlight the urgent need to strengthen STEM education to better prepare and retain students in the fields.

There is evidence that reaching students at earlier pre-college ages pays off in greater numbers of students choosing to pursue a career in engineering, as well as greater understanding of the importance of engineering to the comfort and well-being of people [4][5]. Society as a whole has a need for improved engineering education at the pre-college level to address both shortfalls [6][7].

Project context

The Engineering for Us All (e4usa) curriculum empowers high school students to use what they know and engage in real-world engineering projects that matter to them. Empowerment is built through an awareness of engineering in everyday life, the variety of engineers, and by interrogating and emphasizing how engineering is embedded in society. Engagement occurs as students practice engineering design at multiple scales, considering local and global engineering design challenges.

The curriculum follows a project-based learning pedagogy [9] where student learning is motivated by meaningful cross-disciplinary projects that students perceive as important or real-life, and where students are both sufficiently challenged and have freedom, working in teams, to choose how they will complete the project. This kind of pedagogy aligns with the principle of "thick authenticity" in learning [10]: the idea that practical, real-world learning experiences that encourage students to pursue their own interests, engage them in authentic engineering practices, and use assessment methods authentic to the discipline (e.g. engineering portfolios) will engage student interest and motivation so as to improve learning. Students are provided opportunities to design and create solutions in authentic, student-centered product development challenges.

e4usa invites all schools, teachers, and students to participate fully regardless of their technical background or preparation.The curriculum includes scaffolding for students to support the development of engineering skills. The curriculum is structured around four key themes: discovering engineering, its societal impact, professional skills, and design. These themes are integrated across eight project-based units. Units 1 & 2 introduce engineering as a discipline that shapes everyday life. Units 3 & 4 introduce students to the engineering design process; the class researches a local problem, collaborates with stakeholders, and develops prototype solutions. Units 5 & 6 expand to global challenges, guiding students to design, test, and refine prototypes addressing both global and local issues. Units 7 & 8 encourage students to identify problems in their daily lives, apply the design process, and reflect on their learning. Throughout the course, students engage in increasingly complex engineering projects as they work in teams and record their progress and process in design portfolios. Students develop engineering design and professional skills while learning to think and work like engineers.

The e4usa professional learning offerings are designed to support all teachers, even those with no prior engineering experience. Workshops offer in-depth learning activities; the curriculum is designed to support teachers with background and templates for teachers to tinker with; all new teachers are assigned an experienced teacher as a coach; and e4usa runs a variety of community-building efforts. To foster a sense of community and support, teachers are invited to participate in an online Community of Practice (CoP) that connects them with peers, e4usa team members, university faculty, and practicing engineers throughout the year. CoP sessions are held virtually bi-weekly in two different formats. Once with the coaches in a small peer group and another time with the entire cohort. These sessions encourage teachers to share classroom experiences, exchange lesson plans, and engage in discussions. e4usa team also provides ongoing support through a learning management platform addressing curriculum-related questions and facilitating collaboration and professional growth within the teaching community.

Personas

To achieve its goals, e4usa has treated the curriculum design process as a *Learning Engineering* (LE) [8] design challenge. The team has, at various points, collected data from stakeholders to establish the scope of the challenge and learning objectives; aligned the curriculum with learning theories and pedagogies including project-based learning, thick authenticity, and social cognitive career theory; and developed the curriculum and PD iteratively using feedback and data from teacher and students to guide improvements.

One tool that e4usa is working on using to improve the curriculum through stakeholder feedback and data is *personas*. In LE, personas are a tool for advancing student-centered instructional design, demonstrating potential value in education [11]. Originally from the field of human-computer interaction, a student persona is often represented with a detailed profile that captures the characteristics of a particular segment of students [12]. This tool has been utilized to identify learner needs, shape learning system development, refine teaching strategies, enable role-based activities, and foster broader participation [12]. A persona can either describe characteristics of a subset of learners or of a fictitious learner as a stand-in for that subset of learners; in either case, the purpose of persona development is to account for variations among learners in the target population to inform designs for learning [13].

Personas are increasingly explored in engineering education to understand student needs and improve designs for learning [14][15]. For example, researchers generated four student personas based on survey data from Computer Science and Software Engineering students, identifying factors related to course choice, dropout risks, and areas of interest [16]. Another study developed five work personas representing a variety of career pathways of mechanical engineering design graduates, providing guidance to help students explore career options beyond the traditional [17]. In teaching, researchers tested abbreviated personas in engineering projects and found they supported emotion-driven design decisions [18]. Researchers also identified seven personas in virtual software engineering education, representing common dispositional attributions made by educators, highlighting the risk of misjudging students' character [19]. Additionally, studies show that richer persona details, especially in audio form, could mitigate problems caused by engineering designers making design decisions based on their assumptions about what stakeholders are like [20]. Student personas could help uncover the needs of a wide variety of students [21].

In this study, we discuss the work of addressing personas in pre-college engineering curriculum design. Previous research showed that engaging younger pre-college students in engineering-related activities could increase their interest in pursuing engineering careers and enhance their understanding of how engineering contributes to improving quality of life and addressing human needs [22][23]. High school students' initial interest in STEM is often driven by family support and early extracurricular exposure, while practical lab work helps maintain their engagement [24]. Interactive, team-based learning environments have also been shown to strengthen middle school students' attitudes toward STEM and inspire career aspirations [25]. Furthermore, high school participants in a pre-college civil engineering program regarded hands-on activities and site visits as the most captivating and unforgettable aspects [26]. Through analyzing feedback from students participating in the e4usa, we aim to develop personas that represent the experiences, needs, and perspectives of pre-college learners, with the goal of enriching engineering education in pre-college settings.

Methods

In this paper, our purpose is to examine the responses of students to their experience with the e4usa curriculum. Aligned with sound engineering design practice, part of the process of curriculum development has been to solicit feedback from stakeholders, including students. This has been done through interviews, focus groups, and surveys. In the current paper, we discuss the results of student responses to questions soliciting their opinions about the year-long version of the curriculum as it was tested in the first three years of implementation. Through examining and categorizing students' concerns and preferences, we identify several major concerns as well as appreciated aspects of the curriculum. We also see several dimensions that may be thought of as aligning with different student personas. The purpose of collecting this data and analyzing it has been to improve curricular effectiveness and better align aspects of the curriculum to a broad range of student needs and interests, in line with the e4usa goals to increase both student interest in and preparedness for engineering as a career, and to improve awareness of engineering and its role in society for those students who do not pursue engineering careers. At this time we present only the results of the survey analysis; later we will also address findings from focus groups and interviews.

Data collection and student sample

The e4usa research team surveyed participating students on a variety of topics at the beginning and end of the 2020-21, 2021-22, and 2022-23 school years. e4usa collected surveys from student participants in 50 schools plus one homeschool cooperative. Table 1 describes the age of students. Given that e4usa intends to reach a broad range of students, knowing the age of the students we are working with allows us to know who we are currently serving as well as whose feedback on the curriculum we are reading. This population of students is within 1% and 20% of the US population of K-12 students on a variety of other measures not reported here.

Table 1: Student Demographics – Student Post-Surveys

	N (of 846)	% of Total	N / % of 20-21	N / % of 21-22	N / % of 22-23
Year					
2020-21	179	21.2%	179 / 100%		
2021-22	371	43.9%		371 / 100%	
2022-23	296	35.0%			296 / 100%
Age					
14	72	8.5%	26 / 14.5%	20 / 5.4%	26 / 8.8%
15	218	25.8%	71 / 39.7%	72 / 19.4%	75 / 25.3%
16	174	20.6%	23 / 12.8%	74 / 19.9%	77 / 26.0%
17	215	25.4%	28 / 15.6%	123 / 33.2%	64 / 21.6%
18	137	16.2%	30 / 16.8%	68 / 18.3%	39 / 13.2%
19	14	1.7%	1 / 0.6%	5 / 1.3%	8 / 2.7%
(No Response)	(16)	1.9%	0 / 0%	9 / 2.4%	7 / 2.4%

Survey instrument and coding

The post-surveys included several open-ended questions requesting that students give their opinions on the e4usa course as they experienced it. These questions included:

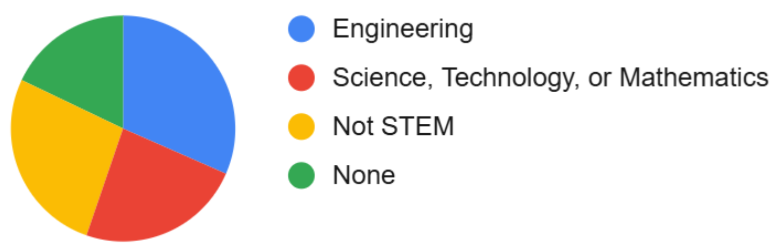
1. What did you like best about this class?
2. What did you like least about this class? (not asked of the 2020-21 students)
3. What would you like to see changed about this class?
4. What do you foresee as your desired profession?

To analyze the data for questions 1-3, one researcher created codes inductively based on student responses. A second researcher re-coded all of the data, adding to the original codes inductively as the need arose. After recoding all three years, the second researcher went back to review the responses and apply codes developed later in the process. Finally, the second researcher organized codes into themes and counted responses both within and across themes. At the present time, the second and a third researcher are working in tandem to refine the codes and conduct interrater reliability analysis; this work is not represented in the current conference paper but will be used in a future journal submission.

The second researcher divided codes into five themes, which will structure the results: STEM-Related Skills and Content (Table 2); Student Feelings, Attitudes, Agency (Table 3); People, Community, and Social Aspects (Table 4); Characteristics of the Course (Table 5); and Other (Table 5). As can be seen in Figure 1, students' responses were most frequently coded one or more times for Characteristics of the Course (47% of codes); 37% of codes referenced STEM-related skills and content. Eight percent of codes related to people, community, or other social aspects as what they liked best about the e4usa class. Four percent of codes discussed students' feelings, attitudes, or agency, and 4% of codes were "other," most of which were no response.

To code question 4 regarding the student's desired profession(s), two researchers coded all of the data from the 2022-23 school year, two researchers classified responses into four categories: "Engineering," "Science, Technology, or Mathematics (STM)," "Not STEM," or "None given" which included null and nonsensical responses as well as "I don't know" [20]. A third researcher extended those codes to the 2021-2022 survey data; the question was not asked in 2020-2021. The results of the coding are shown in Figure 2.

Figure 2: Distribution of professions: "What do you foresee as your desired profession?"



Categorizing personas

To explore personas relating to desired professions and characteristics of feedback provided, we looked at correlations between the various variables we collected from students. We used the 667 student responses from the 2021-22 and 2022-23 school years to examine correlations among students' ages, course opinions, and desired professions. We decided to use the desired profession variables to organize the resulting significant correlations and characterize different categories of students, as our previous discussions with students in focus groups (not reported here) suggested that different students oriented to the class differently based on how it related to their future plans, and this relationship was supported in the correlation data.

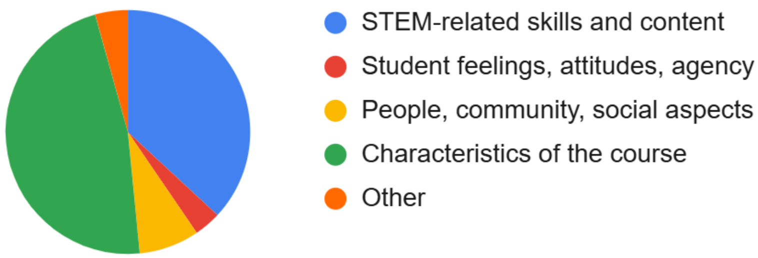
Results

Tables A2-A15 showing coding data can be found in the Appendix.

What did you like best about this class?

Of the 846 surveys, we recorded 47 null responses to this question – 5.5% of responses. For the 799 non-null responses, we coded 1319 separate codes, with up to 3 codes per response. On average, we coded 1.65 separate codes per participant response. The distribution of codes for this question is shown in Figure 1. Data on these responses can be found in Table A6 in the appendix.

Figure 1: Distribution of coded themes – "What did you like best about this class?"



Within the category of STEM-Related Skills and Content (Table A2 in the appendix), we found that students were most enthusiastic about (1) building and testing their prototypes (15% of students), and (2) working cooperatively or collaboratively in teams (13%). The next three areas, favored by between 6% and 8% of students, were designing, the Engineering Design Process more generally, and discovery of new ideas and engineering content.

Table A3 summarizes codes for responses where students discussed their feelings and agency; most commonly, students mentioned their appreciation for being able to make their own choices and decisions in class (4% of responses), though preparing for the future and feelings of accomplishment were also mentioned.

People, community, and the social aspects of e4usa (Table A4) were also common "best" topics. Six percent of students cited the class culture as a positive—another 1% mentioned the supportive nature of the class specifically—and 5% mentioned their teacher.

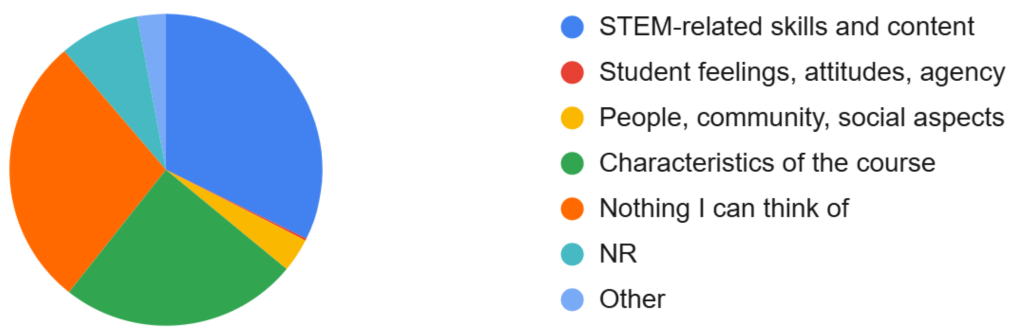
The most commonly coded theme (Table A5) includes all mentions of characteristics of the course. Twenty-two percent of students said that projects were what they liked best, and another 6% mentioned specific projects as their favorite. Hands-on work was cited by 12% of students. Six percent of students mentioned the flexibility and open-ended nature of the course, another six percent appreciated how fun and engaging it was, and another 6 percent the authentic, impactful nature of the work they did.

Overall, students liked best the elements of the class that were hands-on, active, involved building and trying things, let them make choices, and had them collaborating with their teammates and a supportive class culture.

What did you like least about this class?

This question was not asked in 2020-2021; therefore, there are only 705 total participant responses. As with the other questions, we categorized the codes into the same five themes. In Figure 2, we show the distribution of code themes, except that we have broken out "Nothing" from the "Other" theme because it is so common (11%). We find that the majority of codes were assigned to the themes of STEM-Related Skills and Content (41%) and Characteristics of the Course (36%).

Figure 2: Distribution of coded themes – "What did you like least about this class?"



Of the STEM-Related Skills and Content (Table A7), the most-coded were portfolio / documenting (14%) and writing (9%), related (and likely overlapping) aspects of the course. Other common codes for least-liked aspects of the class, all coded for 2 or 3% of responses, include cooperative work, not doing enough engineering, researching, and doing CAD / drawing.

Only 7% of responses were coded as People, Community, and Social Aspects (Table A8). Most of those were complaints about the class culture, particularly frustration with peers who didn't collaborate well with others or contribute to their teams.

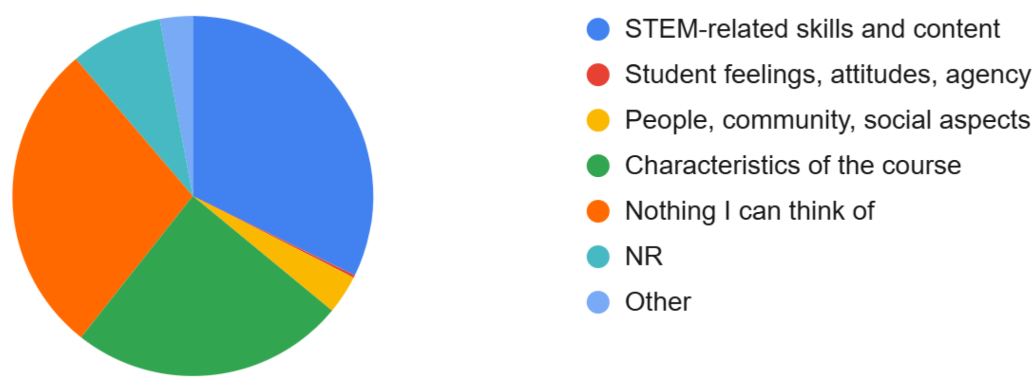
Thirty-five percent of students talked about Characteristics of the Course (Table A10) as something they liked least. The timeframe – including class time management and time allocated to work on projects – was the most commonly cited "least liked" characteristic (6%), followed by challenge level (5% of respondents) and a specific project (4%) – which project was least-liked varied by student. Students also disliked the workload (4%), lack of structure or guidance (3%), or a teaching approach that didn't allow for choosing teammates or flexibility in projects (2%). Two percent of students complained about busy work, and another 2% about failures / making mistakes.

Eleven percent of all respondents said that there was nothing that they liked least about the class. Two students (<1%) said they disliked everything. Six percent of students did not respond to this question. These results can be found in Table A9.

What would you like to see changed about this class?

Of the 846 respondents across three school years (Figure 3), 9% did not respond to this question about what they would like to see changed about this class. Codes were distributed across the same themes, with 32% of all codes related to STEM-related skills and content, 25% related to characteristics of the course, and 4% related to people, community, and social aspects. Twenty-eight percent of codes (31% of respondents) were for the response "nothing" or "nothing I can think of."

Figure 3: Coded themes – "What would you like to see changed about this class?"



A large variety of responses were coded for STEM-related skills and content (Table A11); 7% of students requested improvements to projects and another 7% wanted less time spent on the portfolio and documenting activities. Six percent would prefer more time spent on projects, and 3% wanted more building time. Two percent of students asked for: (1) more time to learn about engineering content or (2) more time to learn about physics or other science content and how to apply it.

Only 2 students requested more opportunities for student agency – making their own choices and decisions (Table A12). Three percent of students requested an improved class culture – particularly an environment with more engaged peers (Table A13).

We saw a variety of requests for improvement to the characteristics of the course (Table A14). The most requested change was for more hands-on work (6%). Students also requested more structure or guidance in the course (4%) or more time to work on projects and prototypes (4%). Other more common requests were for improvements to the teaching approach (3%) or for more resources to create prototypes (2%).

A lot of students (31%) responded that there was nothing they wanted changed about the class, or nothing they could think of (Table A15). A very small percentage of students (<1%) said they wanted *everything* about the class to be changed.

In general, responses to this question, like responses to the other questions, indicate that students prefer hands-on work, projects, and teamwork. They tend to dislike the amount of documentation required for their portfolios, and wish to see more guidance or structure for the class, and spend more time on projects. Most student responses were positive; only a few were very negative overall.

Characterizing Personas

Our first persona is that of the budding engineer: a student who has decided that they might wish to enter an engineering profession. Table 16 shows the correlations of the Profession: Engineering variable with student age and coded themes from questions 1, 2, and 3 described above. We see that students interested in an engineering degree tend to be older. They also tend to complain about some of the STEM skills and content of the course, as well as specific course characteristics.They also were more likely than others to suggest changes to the STEM skills and content, as well as requests to improve student enjoyment and agency within the course. From these relationships, we can deduce (sensibly) that an engineering-career focused student values a class that has strong STEM content and skill support.

Table 16: *Variables Significantly Correlated with Desired Profession: Engineering*

Variable or Theme	Correlation	Significance (1-tailed)
Student Age	0.169	0.000
Q2 Theme: Like least - STEM skills & content	0.164	0.000
Q2 Theme: Like least - Course characteristics	0.084	0.010
Q3 Theme: Desires change - STEM skills & content	0.068	0.045
Q3 Theme: Desires change - Student feelings, attitudes, agency	0.080	0.024

The second persona is of the STM-focused student. These are students who are considering a profession in the sciences, medicine, or other technical or analytic field, but not engineering. These students tend to appreciate the STEM skills and content of the course, but are less likely than others to discuss enjoyment of people and community. They also are more likely to both complain about and make suggestions for improvement to the course characteristics, suggesting that these are, again, students who are serious about STEM content and skills, but that also value people and relationships.

Table 17: *Variables Significantly Correlated with Desired Profession: STM*

Variable or Theme	Correlation	Significance (1-tailed)
Q1 Theme: Like most - STEM skills & content	0.081	0.023
Q1 Theme: Like most - People and Community	-0.085	0.017
Q2 Theme: Like least - Course characteristics	0.088	0.015
Q3 Theme: Desire changes - Course characteristics	0.069	0.043

The third persona is of the non-STEM student. These are students who desire to work in the arts, humanities, business, military, or other non-STEM professions. They are more likely to express appreciation of the people in the class and the class community, less likely to complain about STEM skills and content, and more likely to complain about course characteristics. Like the budding engineers, they also suggest changes to improve student satisfaction, attitudes, and agency in the course.

Table 18: *Variables Significantly Correlated with Desired Profession: non-STEM*

Variable or Theme	Correlation	Significance (1-tailed)
Q1 Theme: Like most - People and Community	0.071	0.038
Q2 Theme: Like least - STEM skills & content	-0.072	0.037
Q2 Theme: Like least - Course characteristics	0.067	0.048
Q3 Theme: Desire changes - Student feelings, attitudes, agency	0.089	0.013

Finally, we discuss characteristics of the students who did not report a desired profession. These students were less likely than others to complain about course characteristics. They also tended to be younger students.

Table 19: *Variables Significantly Correlated with Desired Profession: None*

Variable or Theme	Correlation	Significance (1-tailed)
Student Age	-0.105	0.005
Q2 Theme: Like least - Course Characteristics	-0.112	0.003

Discussion

The evaluation of the e4usa student stakeholders shows that most students value the course and its approach to introducing engineering through project-based learning and thick authenticity, with particular appreciation for hands-on work, teamwork, and real-world challenges. Though students have complaints about the curriculum and how it was implemented in their classrooms, a substantial subset of students had nothing to criticize and nothing they wanted to change. Among those who did criticize the curriculum, most wanted a reduction in the amount of writing and improvement in the focus and support for the documentation required. To improve the course, designers should work to improve students' experiences with project documentation.

Examination of the categories of responses given, both positive and negative, indicate that student interests fall into four main categories, plus "other": (1) STEM-Related Skills and Content; (2) Student Feelings, Attitudes, and Agency; (3) People, Community, and Social Aspects; and (4) Characteristics of the Course. These categories indicate a variety of reasons that students may have to value the course – to increase their engineering and other STEM skills; to feel accomplished and like they have an impact on the world; to work with and have relationships with others, and to have a satisfying educational experience.

Students who anticipate pursuing a career in engineering appear to desire a stronger STEM course, and are more likely to both critique the current content and pedagogy of the course, and to suggest improvements. This makes sense, as these students would tend to be most committed to learning about engineering, and most invested in having a strong course to learn from. The e4usa curriculum should examine students' critiques, particularly those regarding course requirements to document projects, as they may require clearer or stronger scaffolding.

Students interested in STM (not engineering) careers were most likely to appreciate the STEM skills and content of the course, and to critique and make suggestions to improve the course characteristics such as pedagogy. Given such students are more likely than engineering-focused students to appreciate the STEM content, the course curriculum should be examined with an eye to how to better support students looking to enter engineering specifically.

Non-STEM focused students were most likely to appreciate the people and community in the course, such as the class culture, teacher, and support for students. These students were less likely than others to discuss STEM skills and content, and more likely to suggest improvements to address student feelings, attitudes, and agency. Such students do not need this course to support their career plans, and it is most important to them that the course addresses interpersonal needs and desires.

Finally, those who did not report a desired profession tended to be younger than others, and we know little more about them from this analysis.

In further work, we will compare these survey responses to the reasons students give for participating in the course in focus groups and interviews. We will also look in more detail at the specific appreciations and critiques that each persona tended to engage in.

Appendix - Coding Data Tables

Table A2: Like Best - STEM-Related Skills and Content

Category	Definition	Frequency	% of Responses
Building and Testing	Mentions testing and/or building, creating prototypes, or other variations of testing and/or building.	128	15.13%
Cooperative work	Mentions groupwork, teamwork, working with others, or any other moments of collaboration.	113	13.36%
Designing	Includes appreciation of engaging in design work.	65	7.68%
Discovery	Mentions learning new knowledge or similar.	58	6.86%
Engineering Design Process	Either specifically mentions the EDP or specifies more than 3-4 EDP steps.	48	5.67%
Skillset	Cites learning new skills, or using / applying their skills.	19	2.25%
3DModeling/CAD	Mentions CAD, specific CAD software, or 3D modeling.	18	2.13%
Analyzing & Improving	Mentions analyzing results to improve, improving generally, or iteration.	16	1.89%
Researching	Includes specific mention of conducting research.	9	1.06%
Communication	Cites communicating with experts or stakeholders, or learning communication skills relevant to such activities.	4	0.47%
Course content	Cites the course content.	3	0.35%
Learning science/math	Mentions doing or applying math or science skills or knowledge.	2	0.24%
Portfolio	Includes mention of recording or documenting, creating a portfolio, or working in MyDesign.	2	0.24%
Presenting	Cites presenting or showing off their work.	2	0.24%
TOTAL of Participants	Number of survey responses that were assigned one or more “STEM-related skills and content” codes.	401	47.40%
TOTAL of Codes	Number of “STEM-related skills and content” codes assigned.	487	36.92% (of Codes)

Table A3: Like Best - Student Feelings, Attitudes, Agency

Category	Definition	Frequency	% of Responses
Agency for students	Students working independently, making their own choices and decisions.	35	4.14%
Future	Mention of this class preparing or helping students with future jobs, courses, life, or higher-level engineering.	7	0.83%
Accomplishments	Cites the feeling of accomplishment, getting to show things off, feeling of having achieved things	5	0.59%
TOTAL of Participants	Number of survey responses that were assigned one or more “Student feelings, attitudes, agency” codes	47	5.56%
TOTAL of Codes	Number of “Student feelings, attitudes, agency” codes assigned.	47	3.56% (of Codes)

Table A4: Like Best - People, Community, Social Aspects

Category	Definition	Frequency	% of Responses
Class culture	Specifically cites the people (not working with people) and/or the environment in the class.	50	5.91%
Teacher	Calls out the teacher specifically.	46	5.44%
Support	Cites the supportive nature of their class.	9	1.06%
TOTAL of Participants	Number of survey responses that were assigned one or more “People, community, social aspects” codes	95	11.23%
TOTAL of Codes	Number of “People, community, social aspects” codes assigned.	105	7.96% (of Codes)

Table A5: Like Best - Characteristics of the Course

Category	Definition	Freq.	% of Resp.
Projects	Mentions "projects".	193	22.81%
Hands on work	Building things, projects, or prototypes, or "hands on".	101	11.94%
Flexibility	Mentions freedom, open-endedness, availability of choices and different paths.	54	6.38%
Specific project or content	Cites a specific project, type of project, particular activity, or specific content as what they liked best.	52	6.15%
Fun / Interesting / Engaging	Discusses their experience of the class in terms of how it engaged them.	49	5.79%
Authentic or impactful work	Mentions solving real-world problems or applying engineering beyond their classroom.	48	5.67%
Creativity	Mentions creativity, designing, or creating.	36	4.26%
Teaching approach	Mentions enjoying the way the course was taught, or specific approaches to running the class.	30	3.55%
Challenge	Challenging nature of class or addressing challenges.	23	2.72%
Equipment	Discusses the use of power tools, 3d printers, or other manufacturing / building equipment.	22	2.60%
Diversity	Mentions enjoyment of a wide range of topics, learning different things, and diversity in projects.	15	1.77%
TOTAL of Participants	Number of survey responses that were assigned one or more “Characteristics of the course” codes	484	57.21%
TOTAL of Codes	Number of “Characteristics of the course” codes assigned	623	47.23%

Table A6: Like Best - Other

Category	Definition	Freq.	% of Resp.
No Response	No answer given.	47	5.56%
Everything	Says "everything" instead of something specific.	8	0.95%
Nothing	Says "nothing" instead of something specific.	2	0.24%
TOTAL of Participants	Number of survey responses that were assigned one or more “Other” codes.	57	6.74%
TOTAL of Codes	Number of “Other” codes assigned.	57	4.32%

Table A7: Like Least - STEM-Related Skills and Content

Category	Definition	Frequency	% of Responses
Portfolio / documenting	Mentions portfolio or documenting.	99	14.04%
Writing	Mentions writing (other than documenting / portfolio).	65	9.22%
Cooperative work	Mentions working in groups or working with others.	20	2.84%
Not enough doing engineering	Expresses a desire for more engineering or that they expected more engineering.	19	2.70%
Researching	Mentions a dislike of doing research.	18	2.55%
CAD / drawing	CAD, specific CAD software, or online drawing.	17	2.41%
Reading	Mentions reading.	15	2.13%
Planning / scheduling	Cites the process of coming up with or implementing project planning or scheduling.	10	1.42%
Presenting	Mentions presenting to others or creating presentations.	9	1.28%
Coding	Includes anytime a student mentions coding.	7	0.99%
Engineering Design Process	Either specifically mentions the EDP or specifies more than 3-4 EDP steps.	5	0.71%
Projects	Mentions projects in general, or an aspect of projects.	5	0.71%
Communication	Talking with others, communication, contacting stakeholders, or talking with the class.	4	0.57%
Lack of engineering content	Expresses a desire for more engineering-related content, more about specific fields of engineering, etc.	3	0.43%
Building / Testing	Mentions testing and/or building, creating prototypes, or other variations of testing and/or building.	3	0.43%
Content	Content such as: units, general topics, math.	2	0.28%
TOTAL of Participants	Number of survey responses that were assigned one or more “STEM-related skills and content” codes	288	40.85%
TOTAL of Codes	Number of “STEM-related skills and content” codes assigned	301	40.79% (of Codes)

Table A8: Like Least - People, Community, Social Aspects

Category	Definition	Frequency	% of Responses
Class culture	Cites frustration with peers or class environment.	45	6.38%
Lack of women	Cites the lack of women in the class.	1	0.14%
Teacher	Calls out the teacher specifically.	1	0.14%
TOTAL of Participants	Number of survey responses that were assigned one or more "People, community, social aspects" codes	47	6.67%
TOTAL of Codes	Number of "People, community, social aspects" codes assigned	47	6.37% (of Codes)

Table A9: Like Least - Other

Category	Definition	Frequency	% of Responses
Nothing	Response is simply "nothing."	79	11.21%
No Response	No Response	43	6.10%
Everything	Response is simply "everything."	2	0.28%
TOTAL of Participants	Number of survey responses that were assigned one or more "Other" codes	124	17.59%
TOTAL of Codes	Number of "Other" codes assigned	124	16.80%

Table A10: Like Least - Characteristics of the Course

Category	Definition	Frequency	% of Responses
Timeframe	Class time management or time allocated for a project.	44	6.24%
Challenge level	Class is too challenging, too complex, or too easy.	33	4.68%
Specific project	Cites a specific project, activity, or specific content.	31	4.40%
Work / workload	Cites the workload, the type of work assigned, etc.	28	3.97%
Lack of structure	A lack of, or a desire for more, structure or guidance.	21	2.98%
Teaching Approach	The teaching approach, format of the class, extent of freedom, the ability to choose their own groups, etc.	17	2.41%
Busy work	Cites unnecessary work, tedious work, or busy work.	16	2.27%
Failure / mistakes	Frustration with failure or mistakes.	13	1.84%
Exams	Cites quizzes, exams, or the final exam.	12	1.70%
Repetition	Content, projects, topics, or work is repetitive.	12	1.70%
Grading	Cites grading criteria or format / grading of the rubric.	8	1.13%
Lectures	The amount of or length of lectures or slideshows.	6	0.85%
Limited resources	Desire for more / lack of tools and/or resources.	6	0.85%
Videos	Cites the length or content of videos shown in class.	6	0.85%
Boring	Describes the course or an aspect of it as boring.	5	0.71%
Equipment	Use of power tools, 3d printers, or other equipment.	4	0.57%
Lack of flexibility	A desire for more freedom or availability of choices.	3	0.43%
Team exercises	Student cites team building exercises specifically.	1	0.14%
TOTAL of Participants	Number of survey responses that were assigned one or more “Characteristics of the course” codes	246	34.89%
TOTAL of Codes	Number of “Characteristics of the course” codes assigned	266	36.04% (of Codes)

Table A11: Desired Changes - STEM-Related Skills and Content

Category	Definition	Frequency	% of Responses
Improve projects	Request for improvements to projects	57	6.74%
Less documenting	Less time spent on portfolio / documenting	56	6.62%
More projects	More time spent on projects	50	5.91%
More building	More time spent on building prototypes	25	2.96%
More content	More time learning about engineering content	18	2.13%
More physics / science	More time spent learning about physics / other science and how to apply it	18	2.13%
More teamwork	More time spent on teamwork	14	1.65%
Improve content	Improved units, lectures, readings, topics, etc.	8	0.95%
Less drawing / CAD	Less time spent on drawing / CAD	8	0.95%
More drawing/CAD	More time spent on drawing / CAD	7	0.83%
Less teamwork	Less time spent on teamwork	6	0.71%
Less presentations	Less time spent on presentations / sharing	5	0.59%
More contact w/engineers	More time speaking with or hearing from engineers	5	0.59%
More designing	More time spent designing	5	0.59%
More iteration	More time spent improving projects / prototypes	3	0.35%
Less projects	Less time spent on projects	2	0.24%
Less researching	Less time spent on researching	2	0.24%
More coding	More time spent on coding	2	0.24%
Less building	Less time spent on building prototypes	1	0.12%
Less coding	Less time spent on coding	1	0.12%
Less reading	Less time spent on reading	1	0.12%
More math	More time spent learning to apply math	1	0.12%
More presentations	More time spent on presentations / sharing	1	0.12%
TOTAL of Participants	# of survey responses that were assigned one or more "STEM-related skills and content" codes	296	34.99%
TOTAL of Codes	Number of "STEM-related skills and content" codes assigned	296	32.28% (of Codes)

Table A12: Desired Changes - Student Feelings, Attitudes, Agency

Category	Definition	Frequency	% of Responses
More agency for students	request for more opportunities to work independently, making their own choices and decisions	2	0.24%
TOTAL of Participants	Number of survey responses that were assigned one or more "Student feelings, attitudes, agency" codes	2	0.24%
TOTAL of Codes	Number of "Student feelings, attitudes, agency" codes assigned	2	0.22% (of Codes)

Table A13: Desired Changes - People, Community, Social Aspects

Category	Definition	Frequency	% of Responses
Improve class culture	Cites desire for an improved environment in the class and/or more engaged peers	23	2.72%
More people	Cites desire for more students in the class	8	0.95%
Less people	Cites desire for fewer students in the class	1	0.12%
TOTAL of Participants	Number of survey responses that were assigned one or more "People, community, social aspects" codes	32	3.78%
TOTAL of Codes	Number of "People, community, social aspects" codes assigned	32	3.49% (of Codes)

Table A14: Desired Changes - Characteristics of the Course

Category	Definition	Frequency	Responses
More hands-on	More hands-on work	49	5.79%
More structure / guidance	More structure in the class and/or guidance	33	3.90%
More time	More time to work on projects / prototypes	31	3.66%
Improve teaching approach	Requests improvements to teaching approach	26	3.07%
More resources	More resources (tools, materials)	17	2.01%
More authenticity	More authenticity in types of projects	13	1.54%
More challenge	More challenge / difficulty	12	1.42%
More specific content	More of specific content or a particular project	10	1.18%
More fun / interesting	More fun / interesting / engaging course	9	1.06%
Improve exam	Requests improvements to the exam	7	0.83%
More variety	Request for more variety in projects or content	7	0.83%
Improve grading	Requests improvements to grading	6	0.71%
Improve MyDesign	Requests improvements to MyDesign	6	0.71%
Less work / workload	Less work to do / smaller workload	6	0.71%
In person /not virtual	Requests that virtual meetings be held in-person	5	0.59%
Less busy work	Less busy work	5	0.59%
More power tools & tech	More equipment or time with equipment / tools	5	0.59%
Less repetition	Less repetition in lessons, assignments	4	0.47%
Less lecturing	Less time spent on lectures in class	2	0.24%
Less of specific content	Removal of / less of a specific project or content	2	0.24%
More homework	More homework (to free time for in-class work)	2	0.24%
Less challenge	Less challenge / difficulty level	1	0.12%
More creative	More opportunities for creative work	1	0.12%
TOTAL of Participants	# of survey responses that were assigned one or more “Characteristics of the course” codes	208	24.59%
TOTAL of Codes	# of “Characteristics of the course” codes	226	24.65%

Table A15: Desired Changes - Other

Category	Definition	Frequency	Responses
Nothing I can think of	No requests for improvement	258	30.50%
No Response	No response	76	8.98%
Other	Some other unrelated request or statement	22	2.60%
Everything	Expresses dissatisfaction with all aspects of the course	5	0.59%
TOTAL of Participants	# of responses assigned one or more "Other" codes	361	42.67%
TOTAL of Codes	Number of "Other" codes assigned	361	39.37

References

[1] "Employment in STEM occupations," U.S. Bureau of Labor Statistics, https://www.bls.gov/emp/tables/stem-employment.htm (accessed Feb. 20, 2025).

[2] S. R. and A. Burke, "Science & Engineering Indicators," NSF, https://ncses.nsf.gov/pubs/nsb20211 (accessed Feb. 20, 2025).

[3] Danielle Taylor and Caren A. Arbeit, "Science & Engineering Indicators," NSF, https://ncses.nsf.gov/pubs/nsb20245 (accessed Feb. 20, 2025).

[4] K. A. Miller, G. Sonnert, and P. M. Sadler, "The Influence of Student Enrollment in Pre-College Engineering Courses on Their Interest in Engineering Careers," *Journal of Pre-College Engineering Education Research (J-PEER)*, vol. 10, no. 1, May 2020, doi: 10.7771/2157-9288.1235.

[5] B. Homsher, J. Brelin-Fornari, and T. Lynch-Caris, "Impact Of Pre College Program On High School Girls' Interest In Engineering," in *2008 Annual Conference & Exposition Proceedings*, Pittsburgh, Pennsylvania: ASEE Conferences, Jun. 2008, p. 13.692.1-13.692.7. doi: 10.18260/1-2--4068.

[6] Ş Purzer, J.Strobel, & M. Cardella, (Eds.). Engineering in pre-college settings: synthesizing research, policy, and practices. Purdue University Press, 2014.

[7] National Academies of Sciences, Engineering, and Medicine, Building Capacity for Teaching Engineering in K-12 Education. The National Academies Press, Washington, DC: 2020.

[8] J. Goodell and J. Kolodner, *Learning engineering toolkit: Evidence-based practices from the learning sciences, instructional design, and beyond*. Taylor & Francis, 2022.

[9] J. S. Krajcik and N. Shin, “Project-Based Learning,” in *The Cambridge handbook of the learning sciences*, 2nd ed., R. K. Sawyer, Ed., Cambridge University Press, pp. 275–297, 2014.

[10] D. W. Shaffer and M. Resnick, "‘Thick’ authenticity: New media and authentic learning," Journal of Interactive Learning Research, vol. 10, no. 2, pp. 195–216, 1999.

[11] T. Huynh, A. Madsen, S. McKagan, and E. Sayre, “Building personas from phenomenography: A method for user-centered design in Education,” *Information and Learning Sciences*, vol. 122, no. 11/12, pp. 689–708, Jul. 2021. doi:10.1108/ils-12-2020-0256

[12] A. Farooq *et al.*, “Representing groups of students as personas: A systematic review of persona creation, application, and trends in the educational domain,” *Computers and Education Open*, vol. 8, p. 100242, Jun. 2025. doi:10.1016/j.caeo.2025.100242

[13] K. Thai, S.D. Craig, J. Goodell, J. Lis, R. Shoenherr, and J. Kolodner, “Learning Engineering is Human-Centered,” in *Learning engineering toolkit: Evidence-based practices from the learning science, instructional design, and beyond*, J. Goodell, Ed., Routledge, pp. 83-124, 2023.

[14] Exploring the usefulness of personas in engineering education | semantic scholar, https://www.semanticscholar.org/paper/Exploring-the-usefulness-of-personas-in-engineering-Turns-Borgford-Parnell/65881f56bb76a7a79b5479e4cab5b7b5d43d970a (accessed Feb. 20, 2025).

[15] M. Lilley, A. Pyper, and S. Attwood, “Understanding the student experience through the use of Personas,” *Innovation in Teaching and Learning in Information and Computer Sciences*, vol. 11, no. 1, pp. 4–13, Jun. 2012. doi:10.11120/ital.2012.11010004

[16] K. da Branco, R. A. Oliveira, F. L. Silva, J. de H. Rabelo, and A. B. Marques, “Does this persona represent me?,” *Proceedings of the 19th Brazilian Symposium on Human Factors in Computing Systems*, pp. 1–6, Oct. 2020. doi:10.1145/3424953.3426648

[17] X. Ge, M. Schar, H. Chen, G. Toye, and S. Sheppard, “Exploring diverse work personas of Engineering Design graduates through Cluster Analysis,” *2024 ASEE Annual Conference & Exposition Proceedings*. doi:10.18260/1-2--47404

[18] J. Kralick and B. Karanian, “Implementing abbreviated personas into Engineering Education,” *2020 ASEE Virtual Annual Conference Content Access Proceedings*. doi:10.18260/1-2--34778

[19] K. Madhi, L. M. Reimer, and S. Jonas, “Attribution-based Personas in Virtual Software Engineering Education,” *2023 IEEE/ACM 45th International Conference on Software Engineering: Software Engineering Education and Training (ICSE-SEET)*, pp. 235–246, May 2023. doi:10.1109/icse-seet58685.2023.00028

[20] A. M. Schauer, H. Schaufel, M. Nunn, N. D. Kohls, and K. Fu, “Thinking beyond the default user: The impact of gender, stereotypes, and modality on interpretation of user needs,” *Journal of Mechanical Design*, vol. 146, no. 5, Jan. 2024. doi:10.1115/1.4064263

[21] L. O'Brien, T. Kanij, and J. Grundy, "Assessing gender bias in the software used in Computer Science and Software Engineering Education," *Journal of Systems and Software*, vol. 219, p. 112225, Jan. 2025. doi:10.1016/j.jss.2024.112225

[22] K. A. Miller, G. Sonnert, and P. M. Sadler, "The Influence of Student Enrollment in Pre-College Engineering Courses on Their Interest in Engineering Careers," *Journal of Pre-College Engineering Education Research (J-PEER)*, vol. 10, no. 1, May 2020, doi: 10.7771/2157-9288.1235.

[23] B. Homsher, J. Brelin-Fornari, and T. Lynch-Caris, "Impact Of Pre College Program On High School Girls' Interest In Engineering," in *2008 Annual Conference & Exposition Proceedings*, Pittsburgh, Pennsylvania: ASEE Conferences, Jun. 2008, p. 13.692.1-13.692.7. doi: 10.18260/1-2--4068.

[24] A. VanMeter-Adams, C. L. Frankenfeld, J. Bases, V. Espina, and L. A. Liotta, "Students who demonstrate strong talent and interest in stem are initially attracted to stem through extracurricular experiences," *CBE—Life Sciences Education*, vol. 13, no. 4, pp. 687–697, Dec. 2014. doi:10.1187/cbe.13-11-0213

[25] T. D. Ngoc, X. L. Thi, and H. Bui Van, "Improving students' attitudes toward stem and their interest in STEM careers: A collaborative learning approach," *2024 9th International STEM Education Conference (iSTEM-Ed)*, pp. 1–7, Jul. 2024. doi:10.1109/istem-ed62750.2024.10663122

[26] M. Broberg, J. Capa Salinas, and D. Wagner, "A Pre-College Civil Engineering Course: Fostering interest in engineering among high school students and developing Future Engineering Educators," *2023 ASEE Annual Conference & Exposition Proceedings*. doi:10.18260/1-2--42460