Mindset about the Chemical Engineering Major

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Introduction

Chemical engineering (ChE) has the reputation of being a challenging major on account of its rigorous and interdisciplinary curriculum as well as its competitive environment. Understanding complicated concepts, solving complex problems, and handling demanding workloads are general expectations from the ChE undergraduate students. While prior academic training and personal traits can make it easier for some students to tackle the rigorous learning requirements, others might feel overwhelmed and significant mental stress [1,2]. The mental stress could negatively impact students' academic performance [3], which could in turn make them feel discouraged from pursuing ChE [4] or make them feel like they are not good enough. Currently, there is no built-in support system within the curriculum to help students thrive in a rigorous learning environment. Promoting a growth mindset in the ChE curriculum could be an effective strategy in this regard [5].

Growth mindset is the belief that we can develop our abilities over time through learning and effort, while fixed mindset is the belief that we are unable to cultivate our abilities because they are natural and inherent [6,7]. The definitions are based on the implicit theories, the entity and the incremental theories, proposed by Dr. Carol Dweck [8]. People who hold a growth mindset are more likely to thrive in the face of difficulty, while those who hold more of a fixed mindset may shy away from challenges or fail to meet their potential [9]. Cultivating and practicing a growth mindset could not only help students to succeed in the ChE major but also help them to become effective designers in the long run [10]. Innovative design, after all, is iterative in nature, requiring continuous learning and improvement from trial and error. It could also foster a sense of belonging for the students since it can help to reduce stereotypes related to social identities and help students feel supported [11].

We implemented some growth mindset interventions in the course "Mass and Energy Balances (MEB)" a.k.a. "Process Analysis" in the Chemical and Biomolecular Engineering (ChemBE) department of Johns Hopkins University. The interventions were upgraded from our previous efforts [12,13]. We considered Process Analysis to be a good place for the interventions since it is typically the first core course in the ChE major. Experience in this course could influence students' perceptions about the major as well as approaches for navigating it. We applied the interventions during both Fall and Spring offerings of the course in the 2024-2025 academic year. In our institution, the students can take the course either in the Spring semester of their first year or the Fall semester of their sophomore year, depending on their academic progress. We kept the course structures the same in both semesters, and the courses were taught by the same professor. We used a mixed-methods approach to conduct our research. The mindset survey that we used to evaluate students' mindsets analyzed various attributes like developing intelligence, learning new things, receiving feedback, responding to mistakes or failure, and succeeding in the major [12,13]. For

this paper, we chose to present a portion of our overall observation. We focused on the analysis of the students' mindsets about the major. We included specific student responses as part of our analysis and used pseudonyms (fictitious names) to ensure student anonymity. We aimed to answer three research questions:

a) Do gender and school year level affect mindset about the major?
b) What is the general perception of students about succeeding in the major?
c) What is the influence of the course on students' perceptions about succeeding in the major?

Mindset Interventions

We focused on students contemplating and practicing various attributes of a growth mindset during the course. On the first day of the course introduction, we provided some specific advice to the students that would help them to be successful in the course. We emphasized staying up to date in the class through regular attendance and time management, conducting deliberate practice of concepts learnt in the lectures [14], and focusing on continuous improvement. We advised the students to review weekly lecture contents and the associated practice problems by that week to maintain incremental progress, identify any gap in understanding, fill the gap through self-reflection and feedback from the teaching team, and review the content again after getting feedback. For continuous improvement, we advised the students that it's normal to struggle to understand some concepts or not knowing something. It takes time and continuous effort to develop deep conceptual understanding. When they make mistakes or fail to achieve their desired goals, instead of thinking "I can't do it" they should think "I can't do it yet". Then they should continue their efforts and ask for help from the teaching team to improve their performance without worrying about others' judgments.

Throughout the semester, we implemented additional initiatives so that students could reflect on the strategies shared on the first day and pursue them. At the end of each lecture, we reminded students about the steps for deliberate practice. For interested educators, the reminders for deliberate practice can be alternatively provided at the beginning of the weekly lecture practice problems, as sometimes there can be time constraints during the lecture period. In weekly homework, the students reflected on hypothetical scenarios, focused on various attributes of growth mindset, after watching assigned TED talks or YouTube videos. We intended for the students to have a reflection on the utility of these attributes while handling various situations in engineering workplaces. The scenarios and instructions for the homework problems, upgraded from our previous efforts [12,13] are included in Table 1.

Table 1. Mindset interventions applied in specific homework problems during 2024-2025 academic year.

Content of the chosen problem	Hypothetical scenario	Instructions for the students
Generation-consumption analysis	You perform a generation consumption analysis to evaluate a process for producing a particular chemical as a process engineer in a chemical company. You present your analysis during your group's meeting. Your supervisor thinks that although your analysis is good, using a biochemical reaction pathway would be a greener option. He gives you one week to figure out the alternative pathway for producing the product.	Write a response for addressing the prospect of new learning after watching a TED talk [15] on approaching new learning.
Mass balance on a semi-batch process for antibiotic production	As an R&D Scientist in a biotech company you perform lab-scale experiments to determine optimum conditions for antibiotic production in fermentation. At the end of the day, you fail to reach the production goal due to a technical issue. You would need to repeat the experiment.	Write a response for addressing the failed experiment after watching a YouTube video [16] on overcoming obstacles.
Kinetics in a batch reactor	For your graduate research you study reaction kinetics. Your supervisor is not satisfied with the rate constant value you obtained from a recent experiment. She suggests you perform more well-designed experiments to determine the optimum reaction condition that would maximize the rate constant. She provides some suggestions for improving your experiments.	Write a response for addressing your supervisor's feedback after watching a YouTube video [17] on accepting constructive criticism.
Liquid-liquid extraction	As a research scientist you test the purification of a particular product produced in a bioreactor. After determining the required operating condition of the liquid-liquid extractor for a target fractional recovery, you present your analysis to your team members. After the presentation, you realize that you made a mistake in your calculation. You would need to present your analysis again after admitting your mistake.	Write a response for addressing your mistake after watching a YouTube video [18] on owning your mistakes.

We allowed the students to resubmit their quizzes if they scored below 90% [13]. After grading the quizzes, the teaching assistants provided feedback on the students' level of performance using a sliding scale rubric [19]. This way, students could assess their current level of performance and the effort they would need to put to reach the proficient level (90% grade). If the students corrected all the mistakes, they received a 90% grade in their quizzes. We expected that the opportunity for resubmission would help students to treat learning as an evolving process. While this approach worked with most students, some students tried to take advantage of the resubmission opportunity. They stopped studying for the first quiz attempt, since they could get 90% of the grade by working on the quiz at a later time. Interested educators could address this by allocating a specific portion to each quiz attempt (e.g., 60% of the quiz grade for the first attempt and the rest for the revision).

For the group research presentation, the students could improve their work before the final presentation based on feedback from peers, which is also an active learning strategy [20]. We provided students with a specific rubric for peer evaluation to ensure objective judgment. In our previous attempts [12,13], the students received feedback for improving the presentation from the professor, which was no longer feasible due to an increase in the class size. The professor continued emphasizing throughout the semester that learning from mistakes is essential for improving conceptual understanding. It has been reported that when the professor displays a

growth mindset, it also helps to facilitate positive psychological and learning outcomes for students [21,22].

Methods

Researcher Positionality

The first author (she/her) is a teaching-focused faculty in chemical engineering. Her motivation to understand her students' mindsets originated from her own experiences of struggling with academic stress and overcoming them due to having a growth mindset. The second author (she/her/ze/zir), with an interdisciplinary training in Biology, Ethnic Studies, and Education, became interested in mindsets due to her dedication towards cultivating inclusion and belongingness in STEM classrooms. The third author (she/her) is a Master's graduate in mental health counseling with passion for increasing students' mental well-being. The fourth author (he/him) is a teaching-focused faculty in chemical engineering, who collaborated in the earlier mindset studies as another instructor for Process Analysis. He is driven by his own experiences as a student to study ways to improve students' wellbeing and their experiences throughout a course.

Participants

We had total 118 participants combined from both semesters: 69 participants from Fall 2024 and 49 participants from Spring 2025. Among the Fall participants, 42 were women, 27 were men, 58 were sophomores, and 11 were first years. The Spring participants consisted of 27 women, 22 men, 46 first years, and 3 sophomores. All the students received 1% grade incentive for participating in surveys, which were conducted at the end of the semester.

Survey

We conducted an online survey at the end of the semester, consisting of both quantitative and qualitative components, by following an embedded correlational mixed methods design [23]. Our study was considered exempt by the Institutional Review Board of our institution (IRB # 00015411). For the quantitative part, the survey statements regarding the mindset about the major were as follows:

"*Chemical and Biomolecular Engineering (ChemBE) is a challenging major. If you are not smart enough, you will not be able to succeed in the major.*"

"*You can succeed in the ChemBE major through hard work, effective study habits, and perseverance*."

The students responded to these contradictory statements using a 6-point Likert Scale, where the answer could vary from Strongly Disagree to Strongly Agree. For each of these statements, we assigned a score between 1 and 2 as "fixed mindset", a score between 2.1 and 4.9 as "mixed mindset", and a score between 5 and 6 as "growth mindset" [12,13]. For the first statement, we set the scale to assign to 1 to "Strongly Agree" and 6 to "Strongly Disagree". For the second statement, we reversed the numerical assignment for the scale [12,13].

To gain more in-depth understanding of the students' mindsets, we included an open-ended question right after the survey statements, which prompted the students to describe the experiences

or factors that impacted the way they think about succeeding in the major. We also encouraged the students to describe any impact of the course on their thoughts about the major.

Analysis

By following IRB protocol, the second author anonymized the student responses before sharing the data with the first and third authors. Part of this process consisted of assigning pseudonyms to students whose quotes have been included in the qualitative analysis. From the combined quantitative data from Fall 2024 and Spring 2025 (N=118), we calculated mindset score (average $\pm$ standard deviation) for each of the survey statements based on gender and academic level. To determine the impact of gender and academic level on mindset, we used the Wilcoxon rank sum test [24] using $\alpha = 0.05$ in JMP software.

For the qualitative portion of the survey, we had a total of 88 valid responses, 50 responses from Fall 2024 and 38 responses from Spring 2025. We performed thematic analysis to generate themes from the codes [25]. We used an inductive approach [26], in which we derived interpretations from the data directly without making any prior assumptions. We performed two rounds of coding, using in vivo and descriptive coding [25], and generated a codebook to organize the assigned codes.

During the first round of coding, the first, second, and third authors read all the responses line-by-line and assigned codes, which were words or phrases that captured the essence or meaning of the response. We found the inter-rater reliability to be 100%, which was calculated by comparing the overlap of codes for 10 randomly selected data points between the first three authors. The second author then conducted a second round of coding using the qualitative data analysis software NVivo. During this stage, thematically similar codes were collapsed into three primary categories: Innate intelligence/difficult major (codes related to ChemBE being the hardest major and requiring natural intelligence), Hard work/effort (codes related to working hard and persisting through the challenging content), and Impact of course (codes related to the influence of Process Analysis course on students thoughts about the ChemBE major). After an in-depth discussion between the first and second authors, three final themes were developed. While describing each theme in the results and discussion below, we included specific student responses, which were pseudonymized to ensure anonymity. We kept the student responses as they were included in the survey and did not correct any grammatical errors.

Results and Discussion

There was no significant difference (p-value >0.05) between men and women and between first years and sophomores regarding the mindset about the major after combining data from both semesters (Table 2), which was encouraging. This observation answered our first research question, which focused on assessing the influence of gender and school year level on mindset about the major. It also validated the observation from our previous work with a small student population, where we did not observe any gender impact in the mindset intervention group [13]. It was interesting to note that while for the “smartness for success” statement the scores were in the mixed mindset region, for the “hard work for success” statement the scores were in the growth mindset region. Therefore, although there was a unanimous agreement about the importance of hard work to succeed in the major, some students (primarily sophomores) still considered inherent smartness to be a necessity.

Table 2: Mindset score (average ± standard deviation) based on gender and academic level for students combined from Fall 2024 and Spring 2025 (N=118)

Gender	Mindset score (Smartness for success)	Mindset score (Hard work for success)	Academic level	Mindset score (Smartness for success)	Mindset score (Hard work for success)
Women (N=69)	3.94 ± 1.32	5.13 ± 0.94	First years (N=57)	4.12 ± 1.10	5.05 ± 0.93
Men (N=49)	3.90 ± 1.23	5.02 ± 1.09	Sophomores (N=61)	3.74 ± 1.40	5.11 ± 1.07

Our observations from the qualitative analysis supported the quantitative observations and provided additional insights. We generated three themes, which revolved around innate intelligence, hard work, and influence of the course interventions. Through the first theme, we found that some students considered inherent intelligence to be a necessity due to chemical engineering having a reputation of being hardcore. The second theme captured majority of the students agreeing on the importance of hard work for succeeding in the major and some suggesting a baseline level of intelligence and interest in the subject matter as supplemental benefits. The quantitative trends along with the first two themes helped to answer our second research question, which focused on understanding the general perceptions of students about succeeding in the major. Through the final theme, we were able to answer the third research question, which aimed to understand the influence of the course on students' perceptions about succeeding in the major. The theme highlighted the positive impacts of a supportive professor and intentional class design on students' perceptions about the major. We described each theme in more detail below and included relevant student responses, which were pseudonymized.

Theme 1: Innate intelligence is necessary to be successful in the major due to its challenging nature.

There seemed to be a general perception among some students that ChemBE is the most challenging major on campus, which was primarily reinforced by their peers. These participants implied the requirement of minimum level of natural ability to succeed in this major. The names that are used below are pseudonyms, chosen after anonymization. Jared, a first-year student, shared his thoughts on the importance of smartness to pursue ChemBE:

"I think you need to be extremely smart to pursue ChemBE and actually get a good GPA while maintaining a healthy standard of living."

Meanwhile, sophomore Arnold noted that this major is exclusive to those with a certain amount of innate intelligence:

"Chemical engineering is not for everyone and takes a level of intelligence that some don't have."

Finally, Kate, a first-year student, believed that one's innate intelligence is required since the major is very stressful:

"ChemBE is a very mentally taxing major that either has to be compensated for with natural intelligence or a lot of hard work."

The perception of ChemBE as a "very mentally taxing major" that requires lots of "natural intelligence"—for one to be "extremely smart"—that "some don't have" could create a culture of exclusion. These opinions demonstrate that some students have a self-fulfilling prophecy that "Chemical engineering is not for everyone." While we couldn't assume their intentions, these students might contribute to perpetuating the myth that ChemBE is an exclusive club for the smartest students on campus, as though being in this major itself could make someone special.

Theme 2: While hard work ensures success in the major, a baseline level of intelligence and interest in the subject matter can be helpful.

The majority of the students considered hard work to be the most important factor to ensure success in ChemBE while acknowledging that it is a difficult major. They thought hard work paid off more than just being smart. Some students thought that basic intelligence as well as interest in learning the subject could also facilitate success. First-year student Paul reflected on the value of hard work in managing difficult courses:

"I think that while ChemBE is a difficult major, I disagree with the idea that if an individual is not smart enough, they would not succeed. In my experience, putting time into coursework allows for difficult courses to become more manageable."

Meanwhile, Laura, a sophomore, also echoed the same opinion that hard work is the key to success:

"I understand that ChemBE is a challenging major, but I don't believe that being "smart" is the key to success. Everyone has different strengths, and it's not about being the smartest, but about working hard and collaborating with others who bring different skills to the table."

Diego, a sophomore, accepted the "overwhelming" nature of the major. Yet he believed that hard work and curiosity about the subject could sustain one through the major. His response is included below:

"I believe that if you put in the work and effort to learn the material thoroughly, you will do well. It will definitely get overwhelming, as it already has, but as long as you stay motivated, away from burnout, and have at least some interest, it should be fine."

Allen, a sophomore, mentioned the need for some basic intelligence but also acknowledged it being taken into account during the school admission process. He voiced the value of hard work as well:

"I think one needs a base amount of intelligence to succeed in this major, but I also think most people already have that intelligence, especially since this school is relatively selective. Any shortcomings can be made up with hardwork."

While hard work paves the way, the necessity of interest and basic intelligence are important points to consider for thriving in the ChemBE major. Basic intelligence in this context is equivalent to the background knowledge a student is expected to have before joining the University. If there is any lacking in earlier academic training, it can be challenging for the students to keep up with the content as the professors do not always get the chance to cover all the basic information. Also, it can be difficult to put continuous effort, if one is not interested in learning the content.

Theme 3: Inclusive professor and intentional class design positively impact students' perceptions about the major.

Professors who are supportive in their teaching can influence students' perceptions about the major. Brittney, a first-year student, mentioned that the *"[professor] made [her] feel like it's possible to succeed in this major"* although she knew *"it is very challenging and difficult."* She highlighted that the *"[professor] is understanding and supportive and encourages us to not give up and keep trying our best".* Another first-year student Arman felt *"Process Analysis is a hard course, but [professor] is forgiving."*

Some students regarded Process Analysis as an important course for getting an overview of the major, cultivating problem-solving skills, and developing study habits for succeeding in the major. Derek, a first-year student, pointed this out clearly:

"ChemBE is undoubtedly challenging in terms of the level of critical thinking that one must develop and the nature of the content in the major. Process Analysis provides an broad overview of the scope of the major but quickly develops students' problem-solving and intuition. It has demonstrated the importance of solid habits and consistency, which is crucial to overcoming any difficult course or major."

Another first-year student, Jose, revealed that his own mindset was transformed, from being fixed to one of being of growth, after taking the course. His response is as follows:

"There's still definitely people with a 'fixed' mindset that they don't think they're smart enough in the major, but I am no longer one of them after taking this course."

The combination of an inclusive professor and an intentional course design can make a difference in students' mindsets about succeeding in the major. The stereotypical idea that ChemBE is reserved for students with unique intelligence can be changed if the professors take the initiative to upgrade their perceptions and their course structures. We would like to highlight that only one professor and one course would not be sufficient to influence students' mindsets. The initiative needs to happen on a larger scale to notice any significant cultural shift.

Conclusions

We implemented growth mindset interventions in two semesters of the course "Mass and Energy Balances (MEB)" a.k.a. "Process Analysis" in the Chemical and Biomolecular Engineering (ChemBE) department of Johns Hopkins University. Through surveys at the end of the semester, we aimed to understand the influence of gender and school-year level on students' mindsets about

the chemical engineering major, students' general perceptions about succeeding in the major, and the impact of the course interventions. We did not notice any significant difference in mindset scores between men and women and between first-years and sophomores. While students had mixed opinions about the necessity of smartness, they widely acknowledged the value of hard work. Inclusive practices by the professor and intentional course design positively impacted students' perceptions of the major. We hope our observations will motivate chemical engineering educators to reflect on the culture in chemical engineering education and take initiatives towards creating a supportive learning environment for the students.

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