Work in Progress: Promotion of Growth Mindset in Introductory Mass and Energy Balance Course in Chemical Engineering

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Introduction

A growth mindset is a belief that one can develop their abilities through learning and effort, while a fixed mindset is a belief that our abilities are inherent and can not be improved [1]. Having a growth mindset is crucial for successfully designing and implementing a process as a chemical engineer. Innovative design is iterative, requiring continuous learning and improvement as well as consistent effort after setbacks without succumbing to self-doubt, which are the hallmarks of a growth mindset. Interestingly, the standard chemical engineering curriculum, in general, does not have any built-in initiatives to develop a growth mindset in undergraduate students. Therefore, we decided to address this gap as part of curriculum improvement in the Department of Chemical and Biomolecular Engineering (ChemBE) at Johns Hopkins University.

Mass and energy balance is generally the first core course in the undergraduate curriculum of chemical engineering. In our institution, the pre-requisite for this course requires completion of the introductory level chemistry and physics courses. While the students with advanced placement (AP) credits in chemistry and physics typically take the course during the spring of their freshman year, those without any AP credits generally enroll during the fall of their sophomore year. For this study, we chose the students in the Fall 2022 semester to be the control group, while those in the Spring 2023 semester were the intervention group. Therefore, our study period was the 2022-2023 academic year. The course structures were kept mostly similar, with some changes for mindset intervention. Both courses contained the same grade distribution for class participation, weekly group work participation, homework, group project, and the final exam. While the control group had 3 midterm exams, the intervention group had 2 midterm exams and one group research presentation with the same grade distribution.

The goal of our IRB-approved research study was to analyze the impact of gender, racial/ethnic background, and first-generation status on the students' mindsets. In this paper, we reported our preliminary observations from the control group and described the mindset interventions applied to the intervention group. In the future, we intend to report the observations from the intervention group and show the comparisons between the control and the intervention group. As we had a small student population, we considered our work to be a case study.

Study procedure

We implemented a survey of a total of nine questions [2-4] to analyze students' mindsets, where responses were collected using a 6-point Likert scale [2,5]. Instead of keeping all the questions related to intelligence (self-assessment) [2], we included additional questions related to response to feedback, learning new things, and response to making mistake or failure, attributes that are important for innovative design (Table 1). We included an additional question (Q9) to gauge students' perceptions about the chemical engineering major, with long-term implications for the retention of students in the major. The questions represent either a fixed or a growth mindset. For each question, a score between 1 and 2 refers to "fixed mindset", a score between 5

and 6 represents "growth mindset", and a score between 2.1 and 4.9 corresponds to "mixed mindset" [5]. Therefore, for fixed-mindset questions, we set the scale to assign 1 to "Strongly Agree" and 6 to "Strongly Disagree". We reversed the numerical assignment scale for the growth-mindset questions. Before calculating a single mindset score for all the questions together, we calculated a mean mindset score for each question separately to determine if the students' mindsets vary for different attributes. We employed χ^2 test of independence, using α=0.05, to analyze if the students' having a particular mindset has any correlation with under-represented minority (URM) background, gender, or first-generation status. For calculating the single mindset score, we calculated the mean score of each student for Q1-Q9 under a certain category (e.g., female). Then we took an average of those mean scores in that category. We used Cronbach's α to determine the internal reliability or consistency of our whole survey for measuring mindset [5-7]. The statistical analyses were performed using JMP software.

Table 1. The survey questions to analyze the mindsets of students.

#	Question type	Questions	Attributes
1	Fixed	You can learn new things, but you can't really change your basic intelligence.	Intelligence (Self-assessment)
2	Growth	You can always substantially change how intelligent you are through learning.	
3	Fixed	I often get angry when I get feedback about my performance.	Feedback
4	Growth	I appreciate when parents, coaches, teachers give me feedback about my performance.	
5	Fixed	Learning new things is stressful for me and I avoid it.	New learning
6	Growth	An important reason why I do my school work is I like to learn new things.	
7	Fixed	If I make a mistake or fail at something, that means I am not smart at that kind of thing.	Mistake/Failure
8	Growth	If I make a mistake or fail at something, I would want to try to do that thing again.	
9	Fixed	Chemical and Biomolecular Engineering (ChemBE) is known to be a hard major. If you are not smart enough, you won't be able to survive in the program.	Chemical Engineering major

We incorporated the intervention strategies in the regular course environment as part of the weekly group work participation, homework, midterm exams, and group research presentation. During the first week of the semester, we introduced the concept of growth mindset to the students. The students watched a talk by Dr. Carol Dweck, the psychologist who proposed the mindset theory, and Khan Academy's video on growing one's intelligence through struggle during the weekly group work. We encouraged the students to reflect on their own ideas about intelligence and the importance of having a growth mindset while studying chemical engineering. The students then shared their thoughts with their peers. In Table 2, we described the mindset interventions that we applied through the weekly homework. We included a hypothetical scenario at the end of one of the problem statements for every other homework. We asked the students to write a response to the scenario in their own words after watching a relevant YouTube video or TED talk or reading an article. Additionally, we provided the students the opportunity to gain hands-on experiences in learning from mistakes and improving from feedback. For the midterm exams, we allowed the students to work on their mistakes and resubmit the corrected problems to earn some lost points back. For the group presentation, we

provided feedback to each group of students to improve the content and organization of the presentation before the final group presentation at the end of the semester.

Table 2. Mindset interventions planned for specific homework problems.

Content of the chosen problem	Hypothetical scenario	Instructions for the students
Generation-consumption analysis	You perform this analysis while working in a chemical company and present it during a group meeting. Your supervisor thinks that although the analysis is good, the presentation quality is poor. He provides you with some suggestions for improvement.	Write a response for addressing your supervisor's feedback after watching a YouTube video on accepting constructive criticism.
Mass balance on a semi-batch process for antibiotic production	You perform this calculation for an experiment while working as an R&D Scientist in a biotech company. At the end of the day, you fail to reach the production goal due to a technical issue. You need to repeat the experiment.	Write a response for addressing the failed experiment after watching a YouTube video on overcoming obstacles.
Kinetics in a batch reactor	Your graduate research is based on studying reaction kinetics. Your supervisor wants you to find an appropriate enzyme that could make a reaction of interest go faster. She also wants you to find out the synthesis method of the enzyme. You have one week to learn a new method and come up with preliminary experimental plans.	Write a response for addressing the prospect of new learning after watching a TED talk on approaching new learning.
Liquid-liquid extraction	You perform this analysis as an engineer of a clean tech company and present it to your team members. After the presentation, you realize that you have made a mistake in your analysis and you would need to present it again after admitting your mistake.	Write a response for addressing your mistake after reading an article on learning from mistakes.

Preliminary results from the control group

We considered the students from Black/African American, Hispanic, and mixed-race backgrounds to be URM, and the non-Hispanic White and non-Hispanic Asian students to be non-URM. If at least one of the parents completed a college education, a bachelor's degree, or any postgraduate degree (Master's/Ph.D.), we assigned those students a non-first-generation status. Out of the 18 students who voluntarily participated in the survey (without any incentive), the majority were sophomores (78%), identified as female (50%), were from a non-URM background (61%), and had a non-first-generation status (89%).

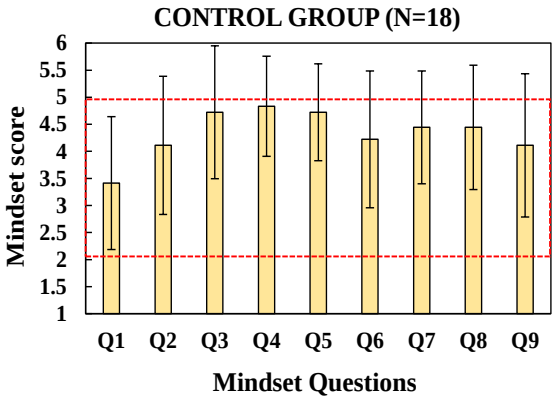

Figure 1: Mean mindset score for each question for the control group (N=18). All the scores are represented as average ± standard deviation.

After calculating the mean mindset score for each question separately, it was evident that the students' mindsets vary for different attributes. For all the questions, the mindset scores were in the mixed mindset region (Figure 1). We did not find any correlation between the students' URM background and mindset for any of the questions (Table 3). However, two interesting correlations did emerge, with calculated χ^2> critical χ^2 and $p < 0.05$ (Table 3).

First, we found that gender and mindset were correlated for the question related to the importance of smartness in the chemical engineering major (Q9). The female students

had a lower score (3.22 ± 1.30) compared to the male students (5.00 ± 0.58) and those who did not identify as either male or female (5.00 ± 0.00) for Q9, suggesting that females have a higher tendency to believe that without being smart one would not be able to survive in the chemical engineering major. This could be attributed to their preconceived notions about the major as well as the environment they experience in the major. This observation made us interested to conduct a separate study with the female students to gain a deeper understanding of the underlying factors that influence their perceptions about the major. As the number of students who did not identify as either male or female was low (N=2), we did not draw any strong conclusions about their mindset related to the major.

Table 3. Determination of correlation between mindset and URM background or gender or first-generation status of the control group (N=18) using χ^2 test of independence (α=0.05).

	URM background		Gender		First-generation status	
Question #	**Calculated χ^2**	**p-value**	**Calculated χ^2**	**p-value**	**Calculated χ^2**	**p-value**
1	2.20	0.33	2.11	0.72	0.90	0.64
2	3.17	0.20	1.37	0.85	2.57	0.28
3	4.41	0.11	1.82	0.77	1.06	0.59
4	2.10	0.15	3.14	0.21	0.00	1.00
5	0.47	0.50	1.57	0.46	4.50	**0.03**
6	1.17	0.56	2.80	0.59	9.14	**0.01**
7	0.69	0.71	8.31	0.08	3.54	0.17
8	1.44	0.49	3.47	0.48	0.32	0.85
9	2.34	0.31	11.27	**0.02**	4.50	0.11

Second, we observed that the first-generation status and mindset were correlated for the questions related to new learning (Q5 and Q6). Specifically, for Q6 the students with non-first-generation status had higher motivation for new learning while doing schoolwork, with a score of 4.50 ± 0.97, compared to those with first-generation status (2.00 ± 1.41). This could be accountable to an inherent motivation of first-generation students to prioritize achieving a better socio-economic status with a college degree over learning new things [8]. Nonetheless, we were cautious about our interpretations, as the data for the first-generation students were insufficient.

Table 4. Single mindset score for the control group (N=18).

Gender	Mindset score	Racial/ethnic background	Mindset score	First-generation status	Mindset score
Female (N=9)	3.95 ± 0.68	Non-URM (N=11)	4.34 ± 0.60	Non-first-generation (N=16)	4.42 ± 0.72
Male (N=7)	4.67 ± 0.56	URM (N=7)	4.36 ± 0.92	First-generation (N=2)	3.78 ± 0.31
Other (N=2)	5.00 ± 0.16				

Note: All the scores are represented as average ± standard deviation.

Finally, we calculated a single mindset score for all the questions together. Cronbach's α of 0.79 supported the adequacy or internal reliability of the survey to measure mindset [6,7]. The single mindset score was in the mixed mindset region for most categories (Table 4). The female students displayed a lower single mindset score (Table 4). Without analyzing the impact of individual questions, it would be difficult to identify the attribute that contributes to this score the most, which is the importance of smartness in the chemical engineering major. While we did not

observe any significant difference in scores between the non-URM and the URM students, the difference was evident for non-first-generation and first-generation students (Table 4). Once again, we were cautious about reaching any conclusion about the mindset of first-generation students due to insufficient data. As the students in the control group displayed mindset scores in the mixed mindset region, we suspected that the scores for the intervention group might not be significantly different. Therefore, we decided to collect qualitative data in addition to the quantitative data for the intervention group at the end of the Spring 2023 semester.

Conclusion

We aimed to understand the impact of the undergraduate students' background on their mindsets and implement growth mindset intervention in the ChemBE department at Johns Hopkins University. We chose the mass and energy balance course for our case study. We reported the preliminary observations from the control group and the interventions applied to the intervention group. The most significant finding from the control group was the correlation between gender and mindset regarding the chemical engineering major, where female students were more prone to believing that smartness is a crucial factor for survival in the major.

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