HOW CHEMICAL ENGINEERING STUDENTS FEEL ABOUT BIOLOGY

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INTRODUCTION

Emotions and attitudes toward a subject can play a large part in a student's decision to take more courses or pursue a major in the subject. For example, engineering students likely have more positive emotions and attitudes toward math, as math is an integral part of engineering disciplines, and thus these students are more likely to pursue engineering careers. The theory of planned behavior [1, 2] outlines this idea in detail as it states that individuals' intentions to pursue a behavior (e.g., major or career choice) are directly tied to their attitudes or feelings toward that behavior. Along these lines, research has shown that positive attitudes toward engineering disciplines result in higher retention rates for engineering majors.[3] However, positive attitudes for engineering disciplines was not uniform across gender, as Besterfield-Sacre has shown that female students have more negative attitudes toward engineering than male students, and this may impact gender diversity in engineering programs.[4]

While it is likely that engineering students have positive attitudes toward math and thus pursue engineering careers because of this, an area in which the opposite may be true is the biological sciences. It has been anecdotally reported that students majoring in the biological sciences have negative attitudes and emotions toward math, which is why they then choose to major in the biological sciences as they perceive these degree programs to have less stringent math requirements. Wachsmuth et al.[5] investigated this claim by developing the Attitudes toward the Subject of Math Inventory (ASMI) which used a semantic differential scale to determine biology students' emotions toward math. A semantic differential scale is one where a participant is asked to rate their feelings or attitudes toward a subject between two opposite pairs of adjectives (e.g., in the Wachsmuth et al. study, students were asked to rate their feelings on "math is…" between the opposite poles of "confusing" and "clear").[6] Their results showed there was a small to moderate effect of major (life science major versus non-life science major) on emotions toward math, with life science majors having more negative emotions toward math than non-life science majors.[5] This was an important finding as it can lead to curricular or course-level changes in biology programs to attempt to promote positive attitudes and emotions toward math within biological sciences students, as math and quantitative skills are becoming increasingly important in modern biological sciences careers.

In this study we were interested in the opposite question as that described above. While we accept the assumption that engineering students have positive emotions and attitudes toward math, it is unknown whether or not engineering students have positive or negative emotions toward biology. This is an important question to answer for chemical engineering educators since biology is becoming an integral part of chemical engineering education, and biological courses are even required in ABET-accredited curricula for chemical engineering programs with the terms "biochemical" or "biomolecular" or similar modifier in their names.[7] Of the 186 ABET accredited chemical engineering programs in the United States, ten of them have the terms "biomolecular" or "biochemical" in their degree names.[8] An analysis of the degree requirements for the top 13 chemical engineering

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programs in the United States shows that 79.6% (10 of 13) either require (8 of 13) or recommend (2 of 13) some type of biology course (e.g., introductory biology, molecular biology, or biochemistry) to earn a four-year chemical engineering degree.[9] Whether or not a degree program requires biology courses, biology is becoming increasingly important in chemical engineering careers; a recent report on the New Directions for Chemical Engineering highlights the importance of chemical engineering in industries such as biomaterials, personalized medicine, and improved therapeutics.[10]

The goals of this study were therefore to 1) determine whether chemical engineering students have positive or negative emotions toward biology and 2) to understand why students have these emotions. Findings from this study will allow for curricular or class-level changes to be made so as to improve chemical engineering curricula in their capacities to address biological topics.

A portion of this manuscript has previously been published as a Work-in-Progress in the 2020 ASEE Conference proceedings.[11] However, the current manuscript has been significantly enhanced in the following ways: 1) expanded data collection to another semester, 2) added results from a new analysis method (semantic differential scale), 3) included additional quantitative results, and 4) included more details in the introduction and discussion.

RESEARCH DESIGN

Study Population

Undergraduate sophomore chemical engineering students in Spring 2019 and Fall 2019 (n = 302) were invited to participate in this study. Sophomore students were chosen as this is the year when they enter the chemical engineering major and enroll in courses such as material and energy balances and introductory thermodynamics and thus can be easily given an in-class survey to complete. Of these students, 246 (81.5%) consented to being in this study and fully participated. The study population demographics were 51.2% male and 48.8% female. Chemical engineering students are required to take introductory biology in order to graduate, and the majority take it during their first year of college. This study was determined to be exempt by the Colorado School of Mines Human Subjects Research Committee.

Data Collection

A single survey was used for data collection in this study. During approximately the middle of each Spring 2019 and Fall 2019 semester, students were given a paper survey in class to complete on a quiz day. This timing was chosen to maximize attendance and to separate this survey from other early and late surveys given at the university. The survey first asked students to rate how well nine word-pairs described their feelings about biology using a semantic differential scale that is used to determine how close to opposing "anchors" a person feels about a certain subject.[5, 6, 12] For example, students rated how much they agree with "biology is confusing" versus "biology is clear" by denoting a score on a seven-point Likert scale, with 1 representing "confusing" and 7 representing "clear." More details on the development of this scale is given in the next section. Students then reported whether they had overall positive or negative emotions toward biology and were asked to explain why they had these feelings. Last, students reported grades earned in prior biology courses and interest in taking future biology courses.

Semantic Differential Scale Development

Our biology emotion semantic differential scale was based on the Attitudes toward the Subject of Chemistry Inventory (ASCI) [12, 13] and the Attitudes toward the Subject of Math Inventory (ASMI),[5] both of which measure students' emotions toward chemistry and math, respectively. The nine pairs of adjectives in our scale were developed by surveying engineering students in an introductory physics course by asking them to "Please list three emotions that you feel when you think of biology. Think carefully and try not to include your feelings toward biology teachers or biology courses." A total of 219 students responded and listed 584 total emotions. The most common responses were used and adapted as the nine pairs of adjectives in the survey. The listing of the semantic differential scale survey is shown in Table 1.

Data Analysis

To quantitatively assess student explanations for their feelings toward biology, an iterative qualitative analysis of the written comments was performed similar to the method used in previous studies.[14-18] Student comments for each survey question were read and coded independently by the two authors of this study. They then met to discuss the emergent themes and agreed upon an initial set of themes. After reviewing the same set of comments, the researchers met again and discussed the validity of the initial set of themes, made appropriate changes, and agreed upon a final set of themes (Tables 2 and 3). The percentage of students who responded with each theme was quantified and presented in a tabular format (Tables 2 and 3).

Inter-rater reliability was determined at the conclusion of the coding process. As a single student's comment tended to have more than one theme applied (e.g., both that biology is interesting and important for humanity), inter-rater reliability was characterized in terms of a complete match (all assigned themes matched between the researchers), a partial match (some, but not all themes matched between the researchers), and no match (no assigned themes matched between the researchers). Overall, 70.3% of the student comments had complete matches, and 29.7% of the comments had partial matches. Any conflicts in themes were discussed until a consensus was reached.

RESULTS

Chemical Engineering Students' Overall Emotions Toward Biology

Table 1 lists the semantic differential scale that was developed in this study. Nine pairs of adjectives were used for students to rate their emotions toward biology on a scale from 1 (positive) to 7 (negative). As shown in Table 1, students on average had positive emotions toward biology for eight of the nine adjective pairs, with the largest positive ratings toward the emotions "interesting" and "stimulating." The only adjective that was rated more toward the negative emotion was "difficult."

TABLE 1
Semantic differential scale for students' emotions toward biology. For each pair of emotions, students (n = 246) rated them from 1 (positive) to 7 (negative) according to the statement "biology is…". Semantic differential terms are presented with the positive emotion equal to 1 and the negative emotion equal to 7, such that ratings less than 4 indicate positive emotions, ratings greater than 4 indicate negative emotions, and ratings equal to 4 represent the midpoint (neutral emotions).

Emotion Pair (Positive-Negative)	Mean	SD
Easy-Difficult	4.37	1.40
Interesting-Uninteresting	2.52	1.73
Clear-Confusing	3.78	1.42
Comfortable-Uncomfortable	3.49	1.46
Satisfying-Frustrating	3.22	1.70
Exciting-Boring	3.08	1.61
Pleasant-Unpleasant	3.45	1.55
Happiness-Sadness	3.45	1.49
Stimulating-Unstimulating	2.92	1.52

Students were next asked to choose in a binary fashion whether they had overall positive or negative emotions toward biology. As shown in Figure 1A, 74.6% of students rated that they had overall positive emotions toward biology. Although there was a slight difference in the overall positive rating for males vs females (79.4% vs 73.3%), this difference was not statistically significant (Chi-square test, $p = 0.263$). There was, however, a significant difference in the positive feeling toward biology between students who were going to enroll in future biology courses (91.9% positive) versus those who were not going to take more biology courses (45.3% positive) and those who were not sure if they would take more biology courses (95.3% positive) (Chi-square test, $p < 0.05$, Figure 1B). Last, students grades in an introductory biology course also played a role in positive emotions toward biology, as more students who earned A grades had positive feelings toward biology (83.5% positive) as compared to those who earned B grades (77.6%) and C grades (69.6%). However, this trend was not significant (Chi-square test, $p = 0.31$, Figure 1C).

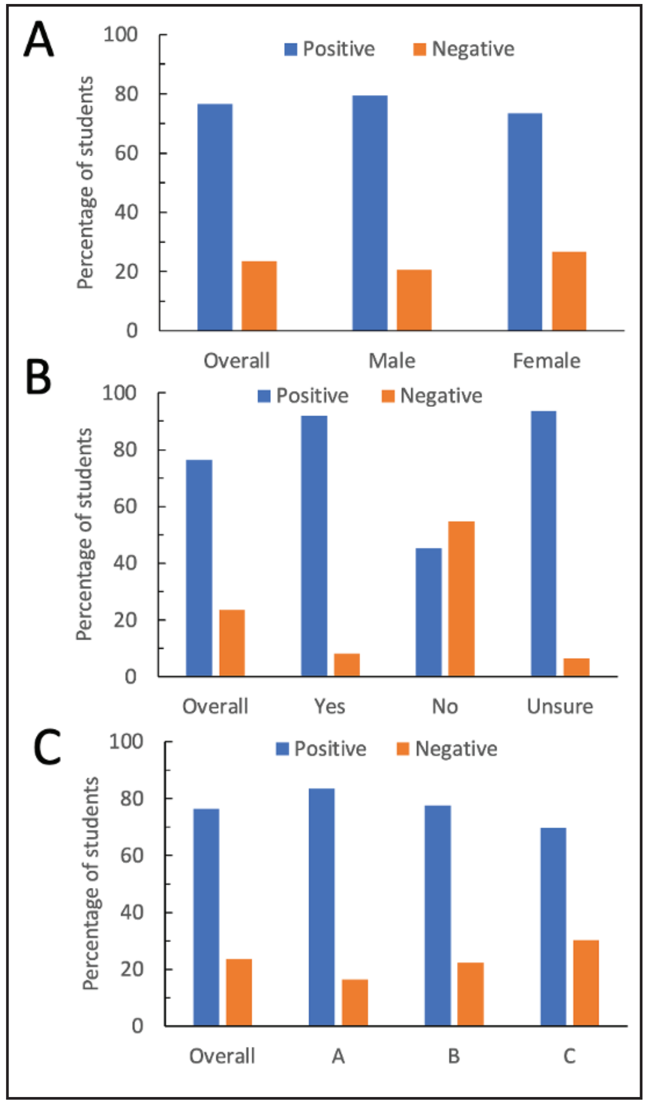

***Figure 1**. Students' emotions toward biology based on (A) gender, (B) desire to enroll in future biology courses, and (C) grade in introductory biology.*

Students' Explanations For Why They Have Positive or Negative Emotions Toward Biology

We next asked students to explain why they had overall positive or negative emotions toward biology. We analyzed comments from 200 students who stated that they had overall positive emotions toward biology, and seven themes emerged from this analysis. As shown in Table 2, students most commonly cited an unspecific positivity toward biology which included aspects of general "likeness," interest, and enjoyment. Over 20% of students also stated that they had positive emotions toward biology because biology is important for humanity and society. Smaller percentages of students stated that they had positive emotions toward biology because biology is important for their own personal career goals or because biology is important for health and medicine in general.

We next analyzed comments from 64 students who stated that they had overall negative emotions toward biology, and six themes emerged from this analysis. As shown in Table 3, students were overall more articulate about why they had negative emotions as compared to positive emotions (Table 2). Almost 30% of students stated that they had negative emotions toward biology because it requires too much memorization. Students also commonly cited poor prior biology course experiences to explain why they had negative emotions toward biology. A small percentage of students had negative emotions toward biology because it is not important for their personal career goals.

DISCUSSION

The major findings from this study are that a majority of chemical engineering students have positive emotions toward biology. Reasons for positive emotions include mostly unspecific enjoyment or interest in biology and that biology is important for humanity, and reasons for negative emotions include mostly perception of the field of biology as memorization heavy and a poor prior biology course experience. Suggestions are provided below for how to incorporate these findings into curricular decisions to improve chemical engineering students' experiences with biology.

We found that by using a semantic differential scale, chemical engineering students scored closer to the positive adjective on eight of the nine adjective pairs used. This finding aligns with the 74.6% of students who stated that they had overall positive emotions toward biology. The only item that scored closer to the negative adjective was that biology is "difficult" as opposed to "easy." This is in agreement with the ASMI in which life sciences students also rated math

TABLE 2
Summary of chemical engineering students' explanations for why they have positive emotions toward biology (n = 228 codes applied to 200 students who left positive comments).

Category	Fraction of surveys with representative comment	Example survey response
Unspecific positivity about biology	26.4%	"I've always been interested in biology which is why I have a positive emotion towards it"
Biology is important for humanity	20.7%	"I think biology can be pretty fascinating and applicable to life"
Enjoy learning about biology	14.1%	"I enjoy the topics, and I feel like it is the most challenging subject for me personally"
Biology as a discipline is interesting	12.8%	"The mechanisms and functions of molecules in life systems is an interest of mine"
Positive biology course experience	12.3%	"I had good teachers and the material was interesting. The labs were fun"
Biology is important for career goals	9.3%	"I want to be more in the biomedical field. My perfect job is combining math, chemistry, and bio"
Biology is important for health or medicine	4.9%	"Biology helps me to know more detail about how body function works"

TABLE 3 Summary of chemical engineering students' explanations for why they have negative emotions toward biology (n = 102 codes applied to 64 students who left negative comments).		
Category	**Fraction of surveys with representative comment**	**Example survey response**
Biology is memorization heavy	29.5%	"Because there is so much material to remember it turns into memorization rather than actual learning and application"
Poor biology course experience	23.6%	"Taking biology felt like a waste of time. I didn't learn anything new and interesting and it was just filled with busy work"
Biology is confusing	16.7%	"I don't enjoy the content of biology and find some of it hard to understand and so I feel more negative towards it"
Biology is boring or uninteresting	13.8%	"Bio is easy and intuitive, but a little boring"
Unspecific negativity about biology	5.0%	"I do not like biology"
Biology is not important for career goals	4.0%	"I do not think that any of it really applies to what I do in my major courses"

as "hard" as opposed to "easy."[5] Perhaps this agreement results from the observation that life science students lack self-efficacy in math and chemical engineering students lack self-efficacy in biology, given that these fields are not at the core of their respective disciplines. On the other hand, the life science students rated math more toward "uncomfortable" as opposed to "comfortable," [5] whereas the chemical engineering students in this study rated biology more toward "comfortable" than "uncomfortable." This may suggest that while not at the core of their major, chemical engineering students find biology more ascertainable than life sciences students find math.

Nearly 24% of students who had negative emotions toward biology cited a poor prior biology course experience to explain their negative emotions. This was nearly double that of the students who cited a positive prior biology course experience to explain their positive emotions. This can likely be explained by the fact that we as humans tend to remember negative experiences more intensely than positive experiences, especially when emotions are involved.[19] Additionally, this highlights the importance of introductory STEM courses in a students' progression through college. Studies have shown that student performance and experiences in gateway STEM courses such as introductory biology, general chemistry, and introductory physics play a large role in a student's decision to continue with their STEM degree.[20-24] If a student has a poor experience in an introductory class and thus has negative emotions toward that field, they are less likely to pursue a career in that discipline. Therefore, this finding from this study contributes to the calls to improve student experiences in college gateway science courses, such as by adding evidence-based teaching strategies such as active learning[25] and high structure course design[26], so as to improve student emotions and attitudes toward different disciplines with the goal of increasing retention.[27, 28] Additionally, instructors can lead outreach efforts to K-12 schools to share information to potential chemical engineering students not only about chemical engineering programs but as a way to begin to introduce biological concepts related to the discipline.[29, 30]

Our results demonstrate that sophomore chemical engineering students have overall positive emotions toward biology. This may thus be used as an impetus to incorporate more biological examples into traditional chemical engineering curricula. Examples of this could include bioenergetics and cellular metabolism in thermodynamics,[31] pharmaceutical membrane filtration in mass transfer and separations,[32] properties of blood flow in fluid mechanics,[33] microbial growth and enzymes in kinetics,[34] aspects of the nervous system, endocrine system, and homeostasis in process control,[35] and hemodialysis[36] and bioreactors[37] in unit operations. Given that over 25% of students reported positive emotions due to biology being important for humanity or health and medicine, it is also possible to include more societal or clinical examples into chemical engineering courses. It would be warranted to survey students concerning their interests in biology and biotechnology before and after using these types of examples in chemical engineering courses to determine if they impart any changes on student attitudes.

Limitations

This study was only performed at one public, STEM-driven institution with two semesters worth of data collected. While the number of participants surveyed was large (n = 246), these were only students in their sophomore year of chemical engineering and thus captured their emotions toward biology at that time in their curriculum. It would therefore be interesting to explore students in their junior and senior years of chemical engineering as well as graduate students, postdocs, and faculty to determine if there are temporal differences. By expanding this study and survey to other types of institutions (e.g., community college, HBCU, private, etc.), we would learn if these results are more broadly applicable to chemical engineering students or are more specific to this study. Additionally, it would be interesting to compare the emotions that chemical engineering students have with other engineering majors who also have strong biological applications such as mechanical, environmental, or computer science, or conversely against engineering majors that have fewer biological applications, such as civil or industrial engineering. This would help determine if the overall positive views toward biology are specific to chemical engineering or are broader to all engineering students. Last, we used a sematic differential scale to collect data on student emotions toward biology. While these data provide an important perspective on student attitudes toward biology, additional factors could be explored in terms of how they contribute to attitudes toward biology including motivation and values[38, 39] and self-efficacy.[40]

Diversity, Equity, and Inclusion

This study did not set out to make a direct contribution to diversity, equity, and inclusion, but the data collection and results can have an impact in this area. All students in our sophomore courses were invited to participate in this study, and we collected survey data from 246 participants, of which 48.8% were female, thus showing a neutral gender balance in our data set. In addition, our results can be used to improve biology curricula for all chemical engineering programs, which typically have higher percentages of female students compared to other engineering disciplines.[41, 42]

CONCLUSION

Our results demonstrate that chemical engineering students have overall positive emotions toward biology. This is a useful finding as biology courses and concepts are being integrated more and more into chemical engineering curricula, and biology is becoming ever more important in 21st century chemical engineering careers.[10] We can use these results to continue to promote the use of biological examples in chemical engineering courses with the understanding of what aspects of biology contribute to students' positive or negative emotions. Additionally, we can reach out to introductory biology instructors to inform them that chemical engineering students generally have positive emotions toward biology so that they can promote biology more specifically to chemical engineering students.

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