AMERICAN SOCIETY FOR MICROBIOLOGY | JMBE Journal of Microbiology & Biology Education

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| Research Article

How students taking introductory biology experience the chemistry content

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ABSTRACT Student experiences learning chemistry have been well studied in chemistry courses but less so in biology courses. Chemistry concepts are foundational to introductory biology courses, and student experiences learning chemistry concepts may impact their overall course experiences and subsequent student outcomes. In this study, we asked undergraduate students enrolled in introductory biology courses at a public R1 institution an open-response question asking how their experiences learning chemistry topics affected their identities as biologists. We used thematic analysis to identify common ideas in their responses. We found that while almost half of student respondents cited learning chemistry as having positive impacts on their experiences learning biology, students who struggled with chemistry topics were significantly more likely to have negative experiences learning biology. We also found significant relationships between prior chemistry preparation, student background, and the likelihood of students struggling with chemistry and negative experiences learning biology. These findings emphasize the impact of learning specific content on student psychosocial metrics and suggest areas for biology educators to focus on to support learning and alleviate student stress in introductory biology.

KEYWORDS chemistry, introductory biology, student experiences, struggle with chemistry

Introductory biology is a gateway course series that allows entry into the biology major and pre-health professional careers. Students often enroll in introductory courses during their first year of college, and such experiences within introductory courses may influence their broader academic and career trajectories (1). Over the past few decades, there have been national calls for introductory courses to move away from "weed-out" cultures (1, 2) and to support classroom environments where students are prepared to be 21st-century scientists and are empowered to succeed (3).

A key skill in biology is the ability to integrate findings from other scientific disciplines, particularly chemistry (3). One of the six core competencies highlighted in the AAAS report, "Vision and Change," is the *ability to tap into the interdisciplinary nature of science*, such as understanding the *chemistry of molecules and biological systems* (3). The National Research Council also provided a framework of crosscutting concepts that link biology and chemistry, including structure and function and transfer of energy and matter (4). Because chemistry concepts like bonds, polarity, and hydrophobicity are so foundational for biology, introductory biology textbooks commonly include one or more chapters devoted to chemistry (5, 6). Therefore, biology educators are increasingly interested in developing curricula or integrated courses that make connections between these two disciplines (7, 8).

However, students often struggle to learn the chemistry material in biology (9–11). Variation in the ways that biology, physics, and chemistry faculty teach about energy and matter can result in confusion and alternative conceptions for students (9, 10). Common

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Authors C.L.M. and M.T.O. were involved in both development and assessment of the chemistry-in-biology intervention presented in this paper. To mitigate potential bias, steps were taken to ensure transparency and methodological rigor. The authors do not stand to gain financially from the success or adoption of the intervention, as it is a non-commercial initiative.

Received 30 June 2024
Accepted 5 August 2024
Published 20 August 2024

alternative conceptions revolve around the particulate nature of matter, covalent bonding, molecules and intermolecular forces, oxidation and reduction, interpreting chemical reactions, and how molecules like ATP store and release energy (12). Indeed, students often struggle to identify cross-cutting concepts and conceptualize chemistry functions in the context of biology (11, 13).

Students' struggles to learn chemistry are compounded by the fact that they often enter biology courses with a range of prior chemistry preparation, from no prior experience to having taken college-level chemistry (14). Students from historically underserved communities, like first-generation college students and PEER (persons excluded by their ethnicity or race) students, may be especially disadvantaged by inequities in preparation because they are less likely to have taken AP Chemistry or other upper-level STEM coursework in high school (15–17). Such inequities are worrisome because students with less preparation in their coursework overall experience lower academic achievement (18). Uneven levels of preparation are also problematic because faculty may assume that students have more prior knowledge than they actually do. For example, while most faculty in a nation-wide survey agreed that knowledge of chemical structures is important for introductory biology students, many faculty also believed this topic was covered in high school and did not need revisiting (5). In contrast, students do, in fact, range in their exposure to and recollection of chemical structures and other basic chemistry concepts (14).

If students have a negative experience with chemistry topics in introductory biology, which is early in their STEM academic career, it could not only impact their attitudes toward chemistry but shape their perception of biology overall. Many studies have shown that how students feel about their learning and belonging in STEM strongly affects whether they choose to continue in STEM (1, 19). Students who left STEM majors due to feeling underprepared often cited difficulties with chemistry coursework (1).

Despite the importance of chemistry learning for biology majors, there is a notable gap in the literature about how a student's experience learning chemistry can impact their experience learning biology. Therefore, in this study, we aimed to uncover various ways students experience learning chemistry in biology contexts and explore what factors might correlate with positive or negative experiences learning chemistry and biology. To fulfill this aim, we surveyed introductory biology students using an open-ended question about their experiences and qualitatively and quantitatively addressed the following three research questions:

1. In what ways does learning the chemistry material affect student's experiences learning biology?
2. To what extent does prior exposure to chemistry and student background correlate with student experience learning chemistry and its effect on the experience of learning biology?
3. To what extent does a chemistry-content-based course intervention affect student experience learning chemistry and its effect on the experience of learning biology?

For research question 1, we hypothesized that learning the chemistry material would affect students in many ways. For research questions 2 and 3, we hypothesized that negative prior chemistry experiences and having less preparation in chemistry could negatively impact student's experiences learning biology, while a chemistry-content-based course intervention would positively help student's experiences in learning biology.

METHODS

Data collection

In order to qualitatively explore the ways learning chemistry material affects student experiences, students enrolled in introductory biology in seven course sections between the Winter 2022 and Spring 2023 academic year at a large public research-intensive university were given a survey at the end of the term which included the open-ended question: "To what extent did your experience with chemistry topics in the beginning of the course influence how you felt about yourself as a biologist in the rest of the term?" Students were also surveyed regarding their demographic information, including race and ethnicity, college-going generation status, and gender. Survey text for analyzed questions is in Supplemental Appendix A. Surveys were optional with potential for extra credit, and within the survey, the open-response question was also optional, with a range of 47%–86% responses across quarters (Table S1). In the quarters with the intervention, the intervention was required for class credit, but students could opt out of having their responses analyzed for research. Ten students opted out of having their responses used for the study. Student responses were removed if they opted out, did not fill out the optional open-ended question, or did not respond to all the demographic questions. After the removal of these responses, the final sample included 1359 student responses.

Students enrolled in the Fall 2022-Spring 2023 academic year received a chemistry-content-based intervention designed to supplement student learning of chemistry in biology topics such as size and scale, chemical structures, chemical bonds, electronegativity, polarity, and hydrophobic and hydrophilic interactions. The full list of learning objectives is given in Supplemental Appendix B. The intervention was delivered on the course management system and consisted of a mandatory pre- and post-assessment of chemistry content knowledge and optional asynchronous chemistry-in-biology supplemental modules. Each module contained a short student-led explainer video covering a chemistry concept and 3–5 practice problems (14). To analyze the effect of module usage on student experiences, students were designated as "pre-intervention" (taking the course in Winter or Spring 2022), "used modules" (taking the course in Fall 2022 or later and using the modules), or "did not use modules" (taking the course in Fall 2022 or later and not using the modules). Module usage was defined as completing at least one practice problem from any of the supplemental modules. Consequently, the "module usage" variable captured active student engagement but did not take into account students who only watched the explainer videos.

Demographic and student characteristics

Student demographics are shared in Table 1. We followed gender-inclusive survey design recommendations and asked students to self-identify their gender using an open-ended write-in question (20). In our study, 20 students identified as non-binary. Because non-binary students represented a small sample size (<1.5%), we included them with women in a "women or non-binary" group because neither of these groups benefit from "perceived traditionally masculine gender" identities (21, 22). Regarding race/ethnicity, students could select multiple race/ethnic backgrounds. Given the smaller sample size for some races and ethnicities, we collapsed students into two groups: PEERs (persons excluded because of ethnicity or race) and non-PEERs (15). We defined PEERs as students who selected Black or African American, Latinx, Native American/Alaska Native, or Native Hawaiian/Pacific Islander as any of their identities. Because of the significant overlap between PEER status and first-generation college-going student status, we created a combined variable that represented both of these historically underserved student backgrounds.

We also collected data on student chemistry preparation. For analysis, we grouped students into the following groups: no prior chemistry preparation, one year or less of high school chemistry, more than one year of high school chemistry, and college chemistry.

Thematic analysis and inter-rater reliability

We performed inductive content analysis on student responses to the open-ended question included in the survey (23). Two co-authors (LM and ATR) separately read through 79 student responses from Winter 2022 and Spring 2022 (10% of the responses

TABLE 1 Student demographic characteristics[a]

Demographics	*N*	Proportion
Gender		
Woman or non-binary	948	0.70
Man	411	0.30
Race/ethnicity		
Asian/ Asian-American	638	0.47
Black or African/American	38	0.03
Latino/a /Chicano/ Hispanic	455	0.33
Native American/Alaska Native	10	0.01
Native Hawaiian/Pacific Islander	25	0.02
White	319	0.24
SWANA (Southwest Asian and North African)	68	0.05
Multi-racial[b]	187	0.14
Historically underserved		
First-generation and PEER	350	0.26
First-generation and non-PEER	290	0.21
Continuing-generation and PEER	148	0.11
Continuing-generation and non-PEER	571	0.42

[a]If a student chose multiple races, they were included in multiple racial or ethnic categories.
[b]This category includes any student who selected more than one racial category.

from these quarters) and identified common codes appearing in the responses. These codes served as the basis of the initial codebook. The co-authors then tested the codebook with another 79 responses, meeting each time to calculate inter-rater reliability using percent agreement, review results, discuss disagreements, and modify the codebook (24). We also calculated Cohen's kappa, which is a measure of inter-rater reliability that takes into account agreement by chance (25). After reaching 90% agreement for all codes, the remaining responses were coded by a single coder. Codes were then grouped into larger themes. Responses from Fall 2022, Winter 2023, and Spring 2023 were coded by LM, AGA, and IV. Each time a new coder joined, the coders went through another process of iterative coding on subsets of the data until reaching 90% agreement.

Statistical analyses

To explore if there was a relationship between various themes, we used chi-square tests with Bonferroni correction for multiple hypothesis testing. Cramer's V was used to calculate effect size.

To identify factors that were significantly associated with the presence of the codes *struggling with chemistry* and *worse experience in biology*, we used logistic regression modeling. We chose this method because it is used for data with two outcomes, such as having or not having a certain code in a student's response (26). When modeling factors associated with the presence of the code *struggle with chemistry*, we included the following possible independent variables: chemistry preparation, historically underserved status, gender, module usage, and the presence of the code *negative prior experience with chemistry*. When modeling factors associated with the presence of the code *worse experience in biology*, we used the variables above as well as the presence of the code *struggle with chemistry*. In both cases, after creating an initial model that included all the possible independent variables, we performed "model selection" using a "best-subset" approach to find the combination of independent variables that would best fit the data while avoiding overfitting (27). More specifically, we tested all possible combinations of the independent variables and compared them using their Akaike information criteria with a penalty for small sample sizes (AICc). AICc is a metric used to estimate the relative "goodness of fit" models, with the best model having the lowest AICc (27). If the two best models were not significantly different by an analysis of variance test and had a difference in AICc that was less than two, we selected the model with fewer independent variables. Logistic regression modeling was performed using the *glm* command in the base package in R (28), and best-subset selection was performed using the dredge function in R's MuMIn package (29). We used restricted maximum-likelihood to fit all models, with the *P* values calculated using *t* tests using Satterthwaite's method.

RESULTS

Chemistry affects student experiences learning introductory biology

To better understand the various ways in which learning the chemistry material affected the experience of learning biology, introductory biology students were asked an open-ended question about how their experiences with chemistry topics at the beginning of the course influenced how they felt about themselves as biologists. Inductive content analysis of 1,359 student responses revealed 6 common themes regarding the ways that learning chemistry affects student experiences learning biology: (i) experience with biology due to chemistry, (ii) struggles with chemistry in the biology course, (iii) prior experience with chemistry, (iv) their attitude toward the chemistry topics, (v) whether the modules did or did not help them, and (vi) surprise about the chemistry topics (Table 2).

We examined the prevalence of each code and associated theme across student responses (Table 2). In the following paragraphs, the names of themes and codes are italicized. We also provide example quotes with the parts relevant to each code in bold. The most common type of student response was a direct answer to the question prompt, with the majority of students (1,104, 81%) sharing their *experiences with biology due to chemistry*. Almost half of the students (662, 49%) shared that because of their experiences with chemistry topics in introductory biology, they had a *better experience with biology*. One student remarked, "**I felt a little bit better about my biology skills**. I was able to recognize patterns throughout the course when it came to different chemistry concepts." Concerningly, 254 students (19%) reported that the chemistry made them have a *worse experience with biology*. For example, one student said, "**It brought me down because I'm not confident in my chemistry skills,** and I disliked how there was chemistry in the bio course in the beginning."

The second most common theme was *struggles with chemistry in the biology course,* with 437 (32%) of students remarking on the challenges of learning chemistry. Most commonly, students focused on the challenges of learning chemistry, with 288 students' responses (21%) mentioning *struggling with the chemistry* concepts. One student shared "**Chemistry has always been a topic I struggled in**, [and] when my peers understood a topic quicker than I did I felt slightly discouraged." Fewer students, 74 (5%) and 75 (6%), respectively, shared that they *did not struggle* or that while they *initially struggled*, their understanding grew over the course of the term. An example of the latter is, "I struggled with some of the chemistry topics at the beginning and had to take the practice exams multiple times when using them, so **at first I felt discouraged. However, after time, these chemistry topics are the ones I feel most confident about in biology** and this helped with questions we had on the first midterm exam."

The third most common theme was *prior experience with chemistry*, with 241 students (18%) having it. Most commonly, students noted that their prior experience with chemistry was helpful or *positive*, with one student remarking, "I had already finished the [lower-level chemistry] series last year and started the [upper-level] series this year so **I had a good understand of all the chemistry topics needed for this course beforehand and it helped** as I had already learned the material was able to use it and focus on it's biological connection and use." Unfortunately, 45 students (3%) expressed that their prior experiences with chemistry had not been helpful or were *negative*. One student wrote, "Since **I have always greatly struggled with chemistry topics, starting from high school,** it felt very difficult and hesitant to view myself as a biologist, since I struggled so much."

TABLE 2 Themes and codes found in student responses[a]

Theme	Code	Description	Example quotation	*N*	%	IRR[b]	Cohen's kappa[c]
Experience with biology because of chemistry	Better	Because of the chemistry topics, they had a better experience in biology.	**"It made me feel much more confident going into the class because I had a strong background knowledge of what we were talking about."**	662	49%	92%	0.973
	Worse	They felt discouraged or worse about themselves as a biologist because of the chemistry topics.	**"My initial struggle made me lack confidence and is probably the reason why I found studying for midterm 1 and 2 so daunting. I just had no confidence in the information I learned."**	254	19%	92%	0.974
	No effect	The chemistry topics did not affect them as a biologist or did not affect their experience with the biology topics.	**"I have taken several chemistry classes. I just don't feel as confident in it so it did not affect how I felt as a biologist."**	188	14%	100%	1
Struggle with chemistry	Did struggle	The student struggled with the chemistry topics.	**"With chemistry being my weakest field when it comes to knowledge**, I'm afraid that it makes me feel as if I can't progress quickly enough to catch up to anyone, or really get to the field."	288	21%	100%	1
	Did not struggle	The student did not struggle with the chemistry topics.	**"My experience with chemistry topics made some material of this course really easy** and helped me think of myself as a biologist."	74	5%	92%	0.740
	Changed	The student initially struggled with the chemistry topics with regard to performance, but their performance improved.	"**It felt very confusing at first, but after getting the practice and strengthening my understanding on chemistry, it felt like I was doing well** with applying it to the biology concepts."	75	6%	96%	0.846
Prior experience with chemistry	Positive	Students had taken chemistry courses previously, which helped them coming into this course.	**"I took upper division courses from the nano department prior to this course. Thus, I was well prepared in chemistry**. The knowledge helped me to understand the fundamentals of topics quickly."	173	13%	100%	1
	Negative	Students had taken chemistry courses previously but it did not help them coming into the course.	**"I did have a background from [chem course] but I still feel that I don't have a good foundation of chemistry**. I feel I learn more chemistry via biology than actual chemistry class."	45	3%	96%	0.652
	No experience	Students had no experience with chemistry coming into the class, and most of the topics were new to them.	**"I had no experience in chemistry,** and although I found it difficult at first, after studying for Midterm 1, I think I was able to sufficiently understand the topic."	23	2%	100%	1
Attitude	Intimidated	When a student expresses fear, intimidation, or another negative emotion around chemistry in this biology course.	"**I do not like chemistry, I was scared that later in the quarter we would be bringing chemistry back**."	75	6%	92%	0.494
	Changed	When a student initially felt fear, intimidation, or another negative emotion around the chemistry topics but their attitude changed.	"None; **I was originally very afraid but after week 2 I realized I really didn't need to be so scared** & that the chemistry knowledge required of us wasn't that hard to understand"	23	2%	100%	1
Whether modules helped	Helped	They used the intervention modules and it was helpful to them when going through the chemistry portion of this class.	"**I will never regret watching those chemistry videos** in the beginning of the quarter **because those videos covered any chemistry concepts that we have covered in this course**."	38	3%[d]	100%	1
	Did not help	They used the intervention modules, and it was not helpful to them for the chemistry portion of this class.	"At the beginning of the course I had already taken two chemistry courses at UCSD but it was as if the questions I've never seen before. **Some were too complicated for my knowledge and I thought the videos didn't help me too much**."	1	0.1%[d]	100%	1

(*Continued on next page*)

TABLE 2 Themes and codes found in student responses[a] (*Continued*)

Theme	Code	Description	Example quotation	*N*	%	IRR[b]	Cohen's kappa[c]
Surprised about chemistry and biology	More	They didn't know how much biology and chemistry connected before this course or were surprised with the chemistry topics	**"I didn't know how much chemistry and biology related to each other** so it makes me think if I am in one science field I am learning about others as well."	23	2%	100%	1
	Less	The student was not surprised by the chemistry topics	**"I knew that chemistry and biology were interconnected** so I didn't mind learning both simultaneously; overall, no influence on my term"	3	0.2%	100%	1

[a]*N* = 1,359. Bolded portions of the quotations represent the relevant coded statements.
[b]IRR = Inter-rater agreement.
[c]Cohen's kappas of 0.41–0.60 are considered to be "moderate" agreement, 0.61–0.80 to be "substantial" agreement," and 0.81–1 to be "excellent" agreement (25).
[d]Calculated out of 862 responses from intervention quarters only.

The final three themes were each expressed by less than 10% of students. These themes were *students being surprised about the amount of chemistry in introductory biology*, expressing *attitudes* or emotions regarding the chemistry topics, and, in the intervention terms, remarking *whether the modules were helpful*.

Factors correlated with student experiences learning chemistry in biology

We noticed that student responses that included *struggles with chemistry in the course* often occurred along with statements regarding *experiences with biology due to chemistry*. We examined the 284 responses that mentioned both the *experience with biology* theme and the *struggle with chemistry* theme (Fig. 1). A chi-square test revealed a significant association between which specific codes from these themes co-occurred [X^2 (4, N = 284) = 160.99, $P < 0.001$] with a large effect size (Cramer's $V = 0.532$). Multiple pairwise comparisons revealed that each comparison was significant (Table S2). Most (81%, 139/172) students who reported struggling with the chemistry topics also reported a worse experience in biology because of the chemistry (Fig. 1). In contrast, 83% (43/52) of the students who reported an initial struggle with the chemistry concepts that got better over time said that they had better experiences in biology because of the chemistry, as did 83% (50/60) of the students who reported not struggling with chemistry (Fig. 1). Notably, none of the students who did *not* struggle with chemistry reported worse experiences in biology. Thus, whether students felt as if they struggled with chemistry at the end of the course was associated with whether the chemistry made their experience learning biology worse or better.

Student struggles with chemistry and their experiences with biology may be impacted by multiple factors, such as demographic characteristics, formal chemistry preparation, and use of classroom materials such as optional intervention modules. To explore the contributions of many factors at once, we conducted two logistic regressions: one to find factors correlated with reporting struggles with chemistry and one for factors correlated with reporting a worse experience with biology. Initial models are available in Tables S3 and S4, respectively, and the final models after model selection are in Tables 3 and 4.

All else equal, students from minoritized backgrounds were significantly more likely to report struggling with chemistry concepts (Table 3). According to the model, a continuing-generation student who is a non-PEER man with college-level chemistry experience would only have an 8.4% chance of reporting that they struggled with chemistry (Table 3). For students with no prior chemistry, the odds ratio was 2.5 (P = 0.02), which means that they were 2.5 times as likely as someone with college-level chemistry to report struggling with chemistry, assuming all other factors were held equal. Similarly, students with only a year or less of high-school chemistry were 2.2 times as likely to report struggling ($P < 0.001$). Students who identified as both first-generation college students and from a PEER background were 2.4 times more likely to report struggling than continuing-generation non-PEER students ($P < 0.001$), and women or non-binary students were 1.8 times more likely to report struggling than men ($P < 0.001$).

For reporting worse experiences in biology because of learning the chemistry material, the main correlative factors centered around experiences and preparation (Table 4). According to the model, a man with college-level chemistry who did not report a negative prior experience with chemistry or struggling with chemistry would only have a 5.5% chance of reporting a worse experience in biology due to chemistry (Table 4). Students who shared they had prior negative experiences with chemistry were 4.1 times as likely ($P < 0.001$) as their fellow classmates to have a worse experience learning biology because of the chemistry concepts. Similarly, students who shared that they struggled with the chemistry concepts were 8.0 times more likely ($P < 0.001$) to report worse experiences. For preparation, students who had no prior chemistry courses were 4.0 times as likely ($P = 0.001$) and students with a year or less of high school chemistry were 2.0 times as likely ($P < 0.001$) to report worse experiences. Women and non-binary

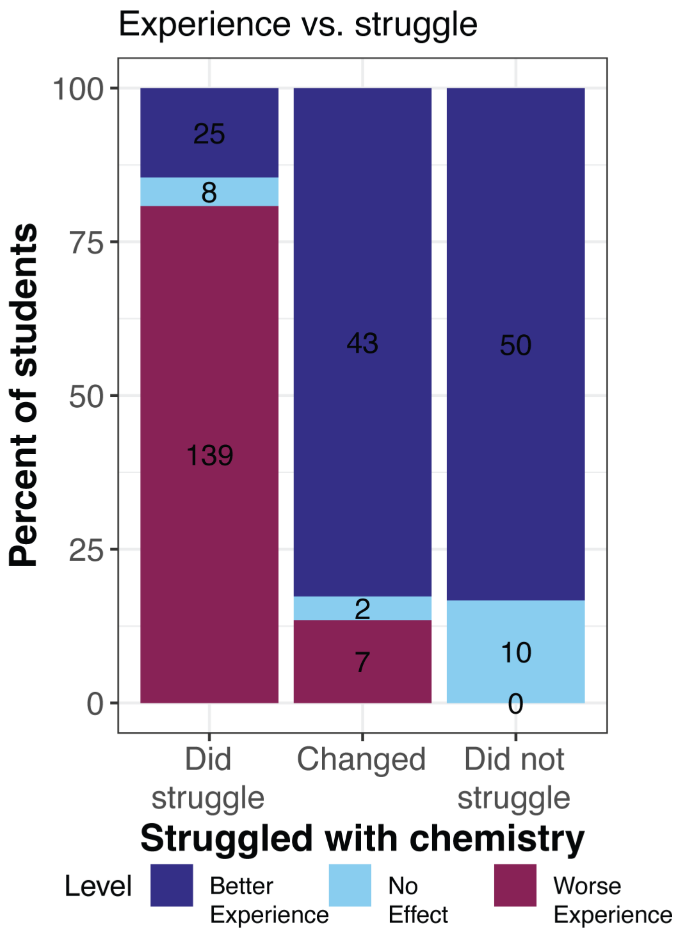

FIG 1 Relationship between chemistry struggle and experience in biology. Percentage of students who did or did not mention "struggle with chemistry" code who had a better, worse, or unchanged (no effect) experience with biology. "Changed" represents students who reported initially struggling but decreased in their struggle. Numbers on each bar represent the number of students.

students were also more likely to report worse experiences in biology (odds ratio = 1.5, P = 0.02).

Effect of a content intervention on chemistry and biology learning experiences

Students enrolled in introductory biology in Fall 2022-Spring 2023 had the option to participate in a supplemental intervention designed to support their learning of

TABLE 3 Final logistic regression model for the presence of the code "struggled with chemistry"[a]

Variable	Estimate (β)	SE	P value	Odds ratio
Intercept (continuing-generation, non-PEER man with college-level chemistry)	−2.47	0.19	<2e−16***	0.084
Continuing-generation, PEER	0.28	0.24	0.24	1.32
First-generation, non-PEER	0.24	0.19	0.22	1.27
First-generation, PEER	**0.88**	**0.17**	**1.25e−07*** **	**2.43**
Woman or non-binary	**0.60**	**0.17**	**0.000287*** **	**1.83**
>One year of high-school chemistry	−0.02	0.25	0.94	0.98
≤One year of high-school chemistry	**0.80**	**0.15**	**6.16e−08*** **	**2.23**
No prior chemistry	**0.94**	**0.39**	**0.018***	**2.52**

[a]Variables with P < 0.05 are bolded. ***P < 0.001.

TABLE 4 Final logistic regression model for the presence of the code "worse experience in biology."[a]

Variable	Estimate (β)	SE	*P* value	Odds ratio
Intercept (man with college-level chemistry who did not report a negative prior experience with chemistry or struggling with chemistry)	−2.88	0.2	<2e−16***	0.055
Woman or non-binary	**0.42**	**0.19**	**0.02***	**1.52**
>One year of high-school chemistry	0.32	0.26	0.23	1.37
≤One year of high-school chemistry	**0.68**	**0.17**	**8.29e−05*** **	**1.97**
No prior chemistry	**1.37**	**0.42**	**0.001** **	**3.95**
Negative prior experiences with chemistry	**1.42**	**0.36**	**7.03e−05*** **	**4.14**
Struggle with chemistry	**2.08**	**0.16**	**<2e−16*** **	**7.97**

[a]Variables with $P < 0.05$ are bolded. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

the chemistry material. Preliminary findings suggest that the use of the intervention modules was associated with improved student academic performance (14).

However, using the optional modules was not significantly associated with differences in student struggles with the chemistry concepts or experience learning biology. The logistic regression modeling originally included the use of the supplemental intervention as a possible variable (Tables S3 and S4). However, this variable was not included in the final parsimonious models because it did not significantly correlate with either struggles in chemistry or worse experiences in biology (Tables 3 and 4). Collectively, these data suggest that while the intervention may have supported student learning, it did not impact student experiences (14).

DISCUSSION

We found that students' experiences with chemistry topics impacted their experiences in introductory biology. While almost half of students reported better experiences, 19% of students reported worse experiences, and 21% of students reported struggling with the chemistry topics (Table 2). Furthermore, student struggles with chemistry and their experiences in biology were associated with one another. All else equal, students who struggled with the chemistry topics were eight times more likely to report worse experiences (Table 4). Emotions influence experiences, and our findings are consistent with research from chemistry courses which found that students reported increasing hopelessness over the course of a term (30).

We also found that students with less chemistry preparation were approximately twice as likely to report struggling with chemistry topics as their classmates (Table 3). While it makes sense that students who entered the course with less prior chemistry experience reported struggling at higher rates than their classmates, as they had further to go in terms of learning the material, it is still concerning because minoritized students are more likely to have attended under-resourced high schools and because students often cite inadequate prior preparation as a reason for switching out of STEM majors (1). We recommend that educators use surveys to identify the range of coursework students may have had prior to entering the classroom and adjust their curricula accordingly.

We also found that students may experience their courses differently in ways related to their identities, which can impact academic performance. Specifically, we found that first-generation PEER students and women or non-binary students were both more likely to struggle with chemistry (Table 3). Various studies within introductory chemistry courses have found that women report lower-self-efficacy, higher test anxiety, and higher anxiety regarding learning chemistry (31, 32). Another study of STEM undergraduate students found that PEER students who reported higher experiences of stereotype threat or worry about confirming competence-deficit stereotypes reported lower motivation and subsequent lower academic achievement (33, 34). Chemistry has a reputation of being a "weed-out" course with high rates of students receiving D, F, or incomplete/withdrawal grades and large equity gaps (1, 35). Given that student performance in introductory courses is associated with retention in STEM and students from underserved backgrounds disproportionately leave STEM (36, 37), these struggles with chemistry have the potential to depress achievement and retention in biology. On the other hand, decreasing equity gaps in chemistry course performance is associated with increased retention for students from underserved communities (35). Efforts to positively impact students' relationships with chemistry through biology courses may, therefore, increase student achievement and subsequent retention.

If students perceive overcoming their struggles with learning chemistry topics, they report better experiences with biology. In our study, a small number of students (6%) reported that while they struggled with the material, their struggles changed over the quarter. The majority of these students reported having a better experience in biology because of chemistry (Fig. 1). These findings suggest that, if overcome, academic challenges do not dictate a student's overall course experience. Supporting students in overcoming academic challenges may help them develop a growth mindset as they navigate their undergraduate education (38). "Wise" interventions that normalize the experience of struggle have been shown to promote positive student experiences and attitudes, and growth mindset interventions, in particular, have reduced equity gaps in chemistry courses (39, 40). These types of messages could be incorporated into future iterations of our intervention.

Limitations and future directions

There are a number of considerations that limit the conclusions that can be drawn from this study. Regarding study design, both the survey and the open-ended question were optional for all students. While we received responses from 62% of enrolled students, that means that 38% of student experiences were not captured in the data. Some studies have found nonresponse effects to skew their sample, while others have found no effects from increasing response rates for college surveys (41, 42).

While we identified a number of factors that contributed to student struggles with chemistry topics, there are likely other factors in and out of class that may influence student struggles. For example, while we surveyed students regarding their prior chemistry preparation, we did not survey students regarding their prior biology preparation. While it is probable that nearly all students had at least one year of high school biology, since that is required for high school graduation in this state, there are a variety of other biology courses that some students could have taken on top of that. The course discussed in this paper is not a prerequisite for this institution's college introductory biology course that focuses on evolution and ecology, so some students could have taken that course first. In addition, some students may have taken additional biology electives or even AP Biology in high school, as at this institution, students need an AP exam score of 4 or 5 to pass out of introductory college biology coursework. While chemistry is not discussed in the evolutionary and ecology course, we would not be able to tell how much chemistry was emphasized in any high school biology coursework a student took. In any case, more experience with biology coursework in general may influence a student's confidence and experience in introductory biology, regardless of their experience with chemistry.

There may also be differences in the likelihood of students from different groups to admit to struggling in chemistry. For example, many male college students feel pressure to keep silent about their academic struggles, which may contribute to the higher likelihood of women reporting struggling with chemistry relative to men in our study (43). Interviews of students who reported struggling with the chemistry topics or worse experiences in biology or with students who actually performed poorly would further identify and flesh out reasons underlying student responses.

Another limitation has to do with how we measured the usage of the intervention's modules. Because we defined module usage as students completing a practice problem, students who only viewed the explainer videos were not counted as having used the intervention. Undercounting the number of students who used the intervention could have contributed to our finding that module usage did not correlate with struggle in chemistry or experience in biology (Tables 3 and 4). Future interventions should additionally assess student use of the videos as another proxy for exposure to the intervention.

Conclusion

Student experiences learning material in introductory gateway courses impacts their decisions to persist or leave STEM majors (1). Our findings suggest that exploring the interdisciplinary concepts and connections to chemistry could be a key area that educators could focus on to improve student course experiences in introductory biology.

ACKNOWLEDGMENTS

This work was supported by the University of California, San Diego, Anti-Racist Pedagogy Learning Community Fellowships to C.L.M. and M.T.O. and by a University of California, San Diego, Academic Senate Research Award to M.T.O. Author A.G.A. was supported by NSF award DUE 2244099.

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DATA AVAILABILITY

Raw data sets are not included, per the guidelines from the human subjects approval, to protect the confidentiality of participants. Anonymized data will be provided upon request.

ETHICS APPROVAL

This study was approved by the Institutional Review Board (Protocol #805097) at the University of California, San Diego.

ADDITIONAL FILES

The following material is available online.

Supplemental Material

Supplemental Appendix (jmbe00111-24-s0001.pdf). Supplemental Appendices A and B and supplemental Tables 1 through 4.

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