Investigating the impact of undergraduate laboratory courses, research experiences, and CUREs courses on lecture-based course material

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Abstract

Undergraduate STEM degrees are composed of lecture and laboratory classes. Additionally, undergraduate research experiences and core-based undergraduate research experience (CURE) are becoming more encouraged throughout a bachelor's degree. However, what is the impact of these courses and experiences on undergraduate education? This study aims to understand the benefit or lack thereof, of laboratory courses, CUREs courses, and undergraduate research experience, on that of lecture courses within STEM degrees. The results were collected by a survey and analyzed for statistical significance using the chi-squared test. Results found that both laboratory courses and undergraduate research experiences had an impact on the lecture courses. This correlation could occur from the re-iteration of the lecture course material within the lab course setting. Further the autonomy in a research experience challenges students to engage in critical thinking, application and analysis of the lecture course material. The results pertaining to the CUREs courses are currently incomplete. There were significantly few respondents who had engaged in a CUREs lab. This could have resulted from the lack of knowledge or awareness of the course. With the continuation of lab courses and a required entry level course focused on entering STEM students into undergraduate research experiences, STEM students' academic output could continue to rise. With a better spread of the CUREs course, the data could be recollected and reassessed.

Introduction

Science, technology, engineering and mathematic (STEM) undergraduate programs implement laboratory courses within their curriculum. These courses are provided to create an engaging environment for the students with the material in a practical manner. They are designed to teach protocols and in turn provide expected experimental results. What are the limitations then, to an educational environment that is premediated in its experimental outcome? STEM students are commonly on the path to higher educational institutions, such as graduate school programs, masters programs or medical schools, where research experience is valued. How comparable then, are the experiences in a teaching lab compared to that of a research lab? Further, what implications do these two experiences have on the outcomes of the typical lecture-based courses conducted during an undergraduate education?

With asking these questions, we can dive into the benefit, or lack thereof, of the educational output obtained by students working in research labs compared to students in only teaching laboratory classes. We can further ask what students gained, from a research laboratory experience, that they may not gain in teaching laboratory classes. Core-based undergraduate research experience (CURE) laboratory courses are the bridge between teaching laboratory classes and that of research experiences. Through these courses we can attest the intersectionality of the information, and further its impact, of a research experience on an undergraduate's education.

Impact of Teaching Laboratory Courses on Lecture Based Courses

Research in “CBE Life Sciences Education: The Effect of a Paired Lab on Course Completion and Grades in Nonmajors Introductory Biology” found that while laboratory classes are made to reinforce the lecture content, they do so in a manner where they lose metacognitive and effective outcomes (DeFeo et al., 2020) Further, the paper goes on to explain that lab experiences do not directly impact students and their outcomes in the adjacent lecture (DeFeo et al., 2020) This unexpected result leads to the question of what the implementation of a research lab as a mandatory requirement for STEM education is. “The Role of the Laboratory in Science Teaching” highlights the important implications of a teaching laboratory within a student’s education. The author of the text claims, “the laboratory is a place of prosper where it engages development in scientific concepts, skills and attitudes” (Tamir, 1976, p. 14). “There is only little value to the experiment if you did not perform it yourself, question it, or modify it in order to provide answers to your queries” (Kingsley, 1890, as cited in Tamir, 1976, p. 7). Here we see the importance in acquiring the ability to produce a hypothesis, conduct experiments to test the hypothesis, critically think and analyze results to further move forward in analyzing the hypothesis. While this is important for teaching laboratories and the ability to think through scientific materials and methods, we wonder how free is one’s thinking in a teaching laboratory where the hypothesis, experiments and predicted results are already thought through for the student?

The paper “Relationship among Laboratory Instruction, Attitude toward Science, and Achievement in Science Knowledge” investigates the achievement of students engaged in laboratory courses and those not engaged in such courses. (Freedman, 1997) Through midterm and final exam assessments, there was a significant increase in the academic output of the students engaged in laboratory courses and those not. The paper concludes this increase to be a result of laboratory courses changing a student’s mind towards science. Furthermore, this increase in attitude towards science indirectly leads to the increase in their achievement in their scientific knowledge.

Impact of Research Laboratory Experiences on Lecture Based Courses

As described in “The Impact of Undergraduate Research Experience Intensity on Measures of Student Success”, undergraduate research is “an inquiry or investigation conducted by an undergraduate student to make an original intellectual or creative contribution to a discipline” (Council of Undergraduate Research, 2018, as cited by Chamely-Wiik et al., 2023). This paper explains how undergraduate research engagement can lead to increased educational metrics for student success, such as persistence and higher GPAs. It was found that students participating in undergraduate research had higher GPAs compared to students not engaging in undergraduate research. In addition, this conclusion was drawn regardless of the outcome. Therefore, in a negative research experience, the undergraduate student was still able to increase their GPA compared to a student who had a more positive undergraduate research experience. (Chamely-Wiik et al., 2023). The paper further analyzed the differences in academic output in regards to experience level in respect to undergraduate research. Students were characterized by either novice or experienced researchers. Novice researchers are described as “students who have completed two or less semesters of undergraduate research” and experienced researchers are described as “students who have completed two or more semesters plus one summer of undergraduate research” (Thiry et al., 2012, as cited by Chamely-Wiik et al., 2023 p. 16). From this differentiation, there was as significant difference between the groups pertaining to their GPA. The experienced students had a significantly higher GPA compared to that of novice students (Chamely-Wiik et al., 2023). This emphasizes that experienced students may be better equipped to transfer research skills to their courses, which can lead to improvements in their courses and their GPA whereas novice students may be less experienced with translating knowledge across the lab bench to the academic desk. This idea brings up the question: what are the knowledge-based skills learned in the lab that can be translated to academia?

Furthermore, the paper “Does exposure to research experiences have different learning outcomes than prior exposure to lab techniques in non-research settings?” found similar results where their study found that research does increase academic output in undergraduate STEM courses. (Beheshtian et al., 2023) This result was concluded through the overall increase in midterm scores for the students engaged in undergraduate research (Beheshtian et al., 2023).

The “Undergraduate Research Experiences Support Science Career Decisions and Active Learning” paper analyzes the Survey of Undergraduate Research Experiences (SURE) to assess undergraduate research experiences. (Lopatto, 2007). The survey asks questions such as “Is the educational experience of undergraduates being enhanced by a research experience?” (Lopatto, 2007, p. 297). The survey pooled 1,135 responses among 41 institutions (Lopatto, 2007). These responses represented a strong positive experience of undergraduate research with learning outcomes. This data was highly replicated from the first findings by Lopatto in 2004. Aside from the high correlation between undergraduate research and learning outcomes in the STEM field, the data was independent of demographics such as field of research, gender, and ethnicity (Lopatto, 2007).

The paper, “Undergraduate students’ involvement in research: Values, benefits, barriers and recommendations” highlights the translational benefits of undergraduate research. Through undergraduate research, students are able to improve the ability to think critically and solve problems by asking insightful questions and critiquing solutions. Critical thinking is emphasized by the hypothesis-driven scientific process. This process demands an understanding of fundamental scientific theories and literature, terminology and technical language pertaining to the topic of interest which, enforces independent critical thinking (Adebisi, 2022). Through independent critical thinking, the undergraduate researcher can build assurance in the scientific process and gain confidence in their own scientific conclusions. Additionally, in taking part in research projects and gaining confidence, undergraduate researchers develop a stronger intrinsic motivation to learn and take on a more active role in learning (Adebisi, 2022). Active learning allows the students to connect with their own interests. Alongside high-levels of interest, undergraduate researchers can have increased enthusiasm and completion rates within STEM which can directly translate into lecture-based courses. Students who want to learn and will interact more with the material, see an increase in their GPA, like that of which was shown in “The Impact of Undergraduate Research Experience Intensity on Measures of Student Success” paper (Chamely-Wiik et al., 2023).

Impact of Core-Based Undergraduate Research Experience (CURE) Laboratory Courses on Lecture Based Courses

Above I have addressed the benefits for undergraduate students engaging a research laboratory setting. However, a research experience is not feasible for all students, so how can students gain research like experience although they are not part of a research laboratory? The answer and research experience lie in core-based undergraduate research experience (CURE) laboratory courses. According to “The COVID-19 and Taste Lab: A Mini Course-Based Undergraduate Research Experience on Taste Differences and COVID-19 Susceptibility”, CURE laboratories allow students to participate in research within a formal laboratory course (Wickham et al., 2023). A key aspect of a CURE course is to include projects that allow for discovery where the experimental outcomes are unknown to both the student and professor (Wickham et al., 2023). Another key aspect pertains to the course and experiment, contributing to an actual scientific study or be beneficial and applicable to a "broader impact" in the overall scientific community (Wickham et al., 2023).

According to "A Novel Undergraduate Biomedical Laboratory Course Concept in Synergy with Ongoing Faculty Research", researched based education branches out into a 2-dimensional framework (Schot et al., 2021). One dimension has the parameters of "teacher-focused" and "student-focused" and the other dimension has the parameters of "research content" and "research processes/problems" (Schot et al., 2021, p. 759). Within these dimensions, 4 scenarios arise to describe the relationship between research and learning. These scenarios include research-led, research-oriented, research-tutored and research-based (Schot et al., 2021, p. 759). The research-led relationship is where information transmission is the main learning method and students learn about research findings (Schot et al., 2021, p. 759). The research-oriented relationship is where students learn of the research processes (Schot et al., 2021, p. 759). The research-tutored relationship is where students learn to write and discuss research papers (Schot et al., 2021, p. 759). The research-based relationship is where students learn as researchers through the scientific process and conduct research themselves (Schot et al., 2021, p. 759). Through these central relationships in CURE courses, undergraduate researchers can think critically through research questions and hypotheses. They can give feedback and provide new scientific ideas. Students are further able to enhance societal relevance of a research topic and move the project forward through asking global questions.

While characterizing the central themes of a CUREs course, "A Novel Undergraduate Biomedical Laboratory Course Concept in Synergy with Ongoing Faculty Research", also emphasize the benefits of undergraduate students participating in these courses (Schot et al., 2021). Alongside "A research program-linked, course-based undergraduate research experience that allows undergraduates to participate in current research on Mycobacterial Gene Regulation", both papers discuss the importance of CUREs within a STEM curriculum (Roberts & Shell, 2022). Through these courses, undergraduate students gain skills similar to those of undergraduate students engaged in research laboratories. CURE enrolled students, gain critical thinking, problem solving, collaboration, scientific writing and experimental setup-based skills (Schot et al., 2021). Specifically critical thinking was enhanced through the engagement with research papers, where they were better able to identify missing controls or parameters of the experiments conducted in the papers. The students also had a better perception of research in a more global scale. The students also gained a significant increase in their critical thinking and communication skills. The increase in skills was due to a newfound autonomy, felt by the student, facilitating motivation and exemplifying the self-determination theory of motivation (Schot et al., 2021). The self-determination theory of motivation claims, that autonomy with feelings of competence and relatedness can help foster deeper learning and academic skill (Schot et al., 2021). Such learning and skills can explain why students who feel like they belong in science, understand the scientific process, and the basis of research, prove to have higher academic scores.

Materials and Methods

A suitable population for this study included students in declared STEM majors at Colorado State University (CSU). These students encompass the variety incorporated within STEM degrees and the value placed on research courses within these degrees. Further, these students understand the rigor incorporated into classwork and research experiences. This population would be able to attest to the benefit, or lack thereof, of laboratory experience, whether class or research, on their academic output. As these students chose STEM degrees, they understand the rigor of the degree and the importance of outside experiences, such as research, on both their further academic career and to the greater wellbeing of the population.

The population within CSU is a fair and representative population. CSU maintains a ratio of 60% in state students and 40% out of state students (‘CSU campuses report increased total enrollment for 2023: News & Media Relations: Colorado State University’, 2023). As these students chose to attend CSU for STEM degrees, they could come from across the country and help to represent multiple geographic demographics.

From this experimental population, possible biases do arise. As this was a survey handed out across many disciplines, non-response bias could arise. This could lead to an underrepresentation of a specific major or discipline. Selection bias can also be present as this was not given to non-STEM degrees. This limits the experiment to only STEM degrees when there are undergraduate research opportunities, and further impacts on academic output, outside of STEM.

Education could present a possible variable within this study. As the survey was passed out degree wide, any year undergraduate student could answer. Freshman and sophomore students might not be exposed, or know of, research opportunities within their degree at university, unlike juniors and seniors. Student’s GPA could be another variable. Students who may not feel confident in themselves and therefore may not choose to answer questions regarding their academic output, unlike students who are proud of their academic achievements. Future research should focus on isolating these main variables to see if, at all, they contribute to the accuracy, or inaccuracy, of these perceptions.

This survey was spread, via email to primary investigator (PI) professors at the Center for Vector-Borne Infectious Disease laboratories at CSU. The email was also spread throughout the Biomedical Sciences and Chemistry Degree programs within CSU. Finally, the survey was provided to honors students via the Honors Weekly Newsletter. The survey was available to students for 4 weeks between August 26th to September 29th. Names of the students were not collected as this was a primarily volunteer-based survey. Responses were collected through Google Forms. The survey started with an introduction to my project, written below, so students could better guide their decision to voluntarily engage or not with the survey.

Welcome and thank you for participating in the survey! This research is aiming to investigate the impact of undergraduate research positions on educational outcomes at Colorado State University. I am specifically looking at how skills and knowledge learned in a research position translates to a lecture and teaching laboratory environment, and vice versa. Through your input, you will provide valuable insight into the impact that undergraduate research has on undergraduate learning within a STEM program.

The first part of the survey began with gathering demographic information regarding what year and what major(s) the students were. The students were then asked about their enrollment in science-based courses at CSU. The courses in question spanned across freshman to senior levels classes.

The classes in question were Life102, MIP300, Life201B, Chem111, Chem113, Chem341 and Chem343. These classes were chosen not only to span the time of an undergraduate in university, but also because of the paired laboratory courses that are meant to reinforce the information learned in the lecture courses. The students were also asked to provide the letter grade they received in the course. With this question, the students had an option of “prefer not to answer” for privacy of the individual. Students than had to answer about their enrollment in the adjacent laboratory courses and further their letter grade in those courses as well. Again, the students were provided with the answer option of “prefer not to answer” in regard to their privacy.

For the second part of the survey, students were asked to rank the benefit of the laboratory section of a class that they were enrolled in. The ranking scale went from 1-10 with 1 being "not helpful at all" and 10 being "very helpful". This was purposeful to identify if any translation between laboratory courses and lecture courses was occurring.

The third part of the survey was essential in identifying any students engaged in research laboratories at CSU, those of which were outside of teaching laboratory courses. To follow up on the impact of research laboratories on academic output, the students were asked if their laboratory work brought any clarity to either a teaching laboratory or lecture course.

The fourth part of the survey pertained to student enrollment, or not, within a CUREs laboratory course. This was purposeful to incorporate the undergraduate research that intersects between a teaching lab and an undergraduate research experience.

All collected data was analyzed using the chi-squared statistics as written in *figure 1.* The calculated chi-squared values were compared to the α value of 0.05 to determine statistical significance.

$$\text{Chi} - \text{squared} = \Sigma \frac{(observed\ value - expected\ value)^2}{expected\ value}$$

Figure 1: Chi-squared equation.

Results and Analysis

Population Details and Demographics

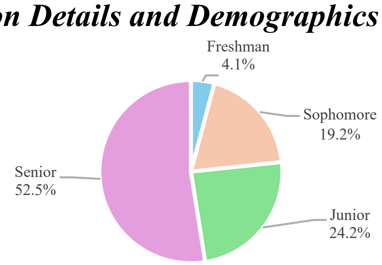


Figure 2: Distribution of respondents' collegiate year.

The surveyed population indicated 120 repsonses. 53% of respondents consisted of seniors, 24% juniors, 19% sophomores, and 4% freshman from Colorado State University (CSU), as shown in *figure 2*. The high percentage of seniors could lead to bias as those students have been in STEM majors for a long time, and know or have access to more laboratory opportunities or resources.

The 120 respondents had a range of 15 different STEM majors, as shown in *figure 3*. Through this variety, there is a lower risk of bias towards one specific major. 5.8% of respondents are Engineering majors. 38.3% of the respondents are Biomedical Sciences majors. 3.3% of respondents are Wildlife Biology majors. 17.5% of the respondents are Biology majors. 0.8% of the respondents are Chemistry majors. 0.8% of the respondents are Mathematics majors. 4.2% of the respondents are Biochemistry majors. 1.7% of the respondents are Architecture majors. 0.8% of the respondents are Agriculture majors. 10.8% of the respondents are Animal Sciences majors. 5.8% of the respondents are Zoology majors. 2.5% of the respondents are Fermentation Sciences majors. 1.7% of the respondents are Ecosystem Science and Sustainability majors. 2.5% of the respondents are Nutrition majors. 3.3% of the respondents are Health and Exercise Science majors.

Lectures and Teaching Laboratory Courses

Life102 lecture course, is a course for first year STEM undergraduate students. 73.3% of respondents have taken the Life102 lecture course, whereas 26.7% of the respondents have not, as shown in *figure 4 A.* The grades of the 73.3% of the respondents who took Life102 lecture were analyzed, as represented in *figure 4 B.* 88.6% of the repsondents achieved an A in the course, 9.1% achieved a B, 2.3% achieved a C, 0% achieved a D, F, or preferred not to say their grade.

Life102 lab course, is a course for first year STEM undergraduate students in conjunction with the Life102 lecture course. 73.3% of respondents have taken the Life102 lab course, whereas 26.7% of the repsondents have not, as shown in *figure 4 C.* The grades of the 73.3% of the respondents who took Life102 lab were analyzed, as represented in *figure 4 D.* 72.7% of the repsondents achieved an A in the course, 22.7% achieved a B, 3.4% achieved a C, 1.1%

achieved a D, 0% achieved an F or preferred not to say their grade.

The comparison of Life102 lecture grades and Life102 lab grades are represented by *figure 4 E.* For the letter grade A, there is a 15.9% difference, with more As achieved in the lab course. For the letter grade B, there is a 13.6% difference, with more Bs achieved in the lecture course. For the letter grade C, there is a 1.1% difference, with more Cs achieved in the lecture course. For the letter grade D, there is a 1.1% difference, with Ds only being achieved in the lecture course. For the letter grade F and the preference not to answer, there is no difference between the courses.

Chem111 lecture course, is a course for first year STEM undergraduate students. 89.2% of respondents have taken the Chem111 lecture course, whereas 10.8% of the repsondents have not, as shown in *figure 5 A.* The grades of the 89.2% of the respondents who took Chem111 lecture were analyzed, as represented in *figure 5 B.* 67.3% of the respondents achieved an A in the course, 23.4% achieved a B, 8.4% achieved a C, 0% achieved a D or F, and 0.9% preferred not to say their grade.

Chem112 lab course, is a course for first year STEM undergraduate students in conjunction with the Chem111 lecture course. 86.7% of respondents have taken the Chem112 lab course, whereas 13.3% of the repsondents have not, as shown in *figure 5 C.* The grades of the 86.7% of the respondents who took Chem112 lab were analyzed, as represented in *figure 5 D.* 86.5% of the repsondents achieved an A in the course, 9.6% achieved a B, 1.9% achieved a C, 0% achieved a D or F, and 1.9% preferred not to say their grade.

The comparison of Chem111 lecture grades and Chem112 lab grades are represented by *figure 5 E.* For the letter grade A, there is a 19.2% difference, with more As achieved in the lab course. For the letter grade B, there is a 13.8% difference, with more Bs achieved in the lecture course. For the letter grade C, there is a 6.5% difference, with more Cs achieved in the lecture course. For the letter grade D and F, there is no difference between the lecture and lab course. There is a 1% difference in respondents who preferred not to say their grade, with a higher preference in the lab course.

Chem113 lecture course is a contingent of the Chem111 course for first-year STEM undergraduate students. 84.2% of respondents have taken the Chem113 lecture course, whereas 15.8% of the repsondents have not, as shown in *figure 6 A.* The grades of the 84.2% of the respondents who took Chem113 lecture were analyzed, as represented in *figure 6 B.* 53.5% of the respondents achieved an A in the course, 34.7% achieved a B, 6.9% achieved a C, 2% achieved a D, 0.8% achieved an F, and 2% preferred not to say their grade.

Chem114 lab course is a contingent of the Chem112 course for first year STEM undergraduate students. 80% of respondents have taken the Chem114 lab course, whereas 20% of the repsondents have not, as shown in *figure 6 C.* The grades of the 80% of the respondents who took Chem113 lecture were analyzed, as represented in *figure 6 D.* 82.3% of the respondents achieved an A in the course, 13.5% achieved a B, 3.1% achieved a C, 1% achieved a D, 0 % achieved an F or preferred not to say their grade.

The comparison of Chem113 lecture grades and Chem114 lab grades are represented by *figure 6 E.* For the letter grade A, there is a 28.9% difference, with more As achieved in the lab course. For the letter grade B, there is a 21.2% difference, with more Bs achieved in the lecture course. For the letter grade C, there is a 3.8% difference, with more Cs achieved in the lecture course. For the letter grade D, there is a 1% difference, with more Ds achieved in the lecture course. For the letter grade F, there is a 1% difference, with only Fs achieved in the lecture course. There is a 2% difference in respondents who preferred not to say their grade, with a

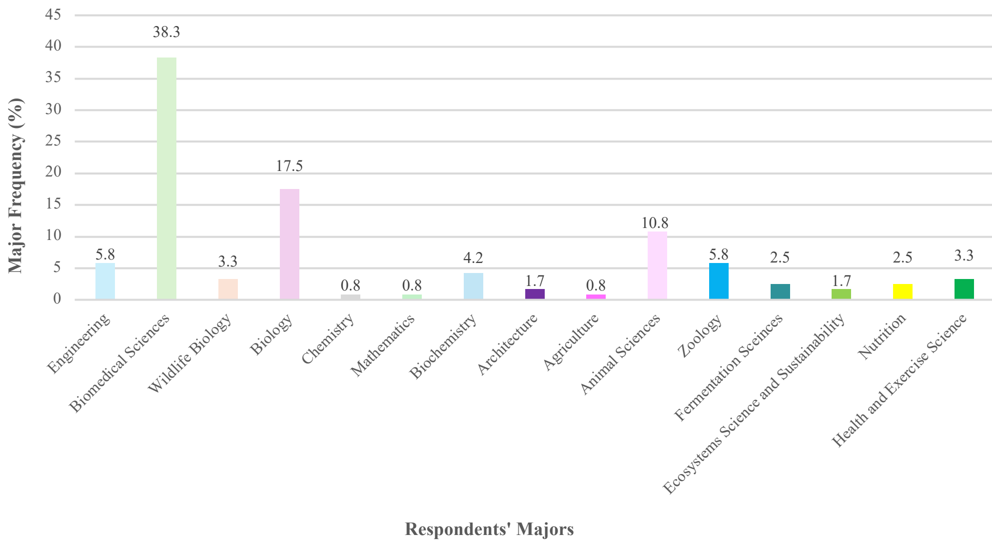


Figure 3: Distrubtion of respondents' major.

higher preference in the lecture course.

Life201B lecture course is a biology course available to second-year STEM undergraduate students. 12.5% of respondents have taken the Life201B lecture course whereas 87.5% of the repsondents have not, as shown in *figure 7 A.* The grades of the 12.5% of the respondents who took Life201B lecture were analyzed, as represented in *figure 7 B.* 66.7% of the respondents achieved an A in the course, 20% achieved a B, 13.3% achieved a C, 0% achieved a D, F, or preferred not to say their grade.

Life201B lab course is a biology laboratory course available to second year STEM undergraduate students in conjunction with the Life201B lecture course. 12.5% of the respondents who took Life201B lab were analyzed as represented in *figure 7 D.* 73.3% of the repsondents achieved an A in the course, 20% achieved a B, 6.7% achieved a C, 0% achieved a D, F, and preferred not to say their grade.

The comparison of Life201B lecture and lab grades are represented by *figure 7 E.* For the letter grade A, there is a 6.6% difference, with more As achieved in the lab course. For the letter grade B, there is a 0% difference. For the letter C, there is a 6.6% difference, with more Cs achieved in the lecture course. For the letter grade D, F, and preference not to say their grade, there is no difference between the lecture and lab course.

MIP300 lecture course is a microbiology course available to second and third year STEM undergraduate students. 40% of respondents have taken the MIP300 lecture course, whereas 60% of the repsondents have not as shown in *figure 8 A.* The grades of the 40% of the respondents who took MIP300 lecture were analyzed as represented in *figure 7 B.* 52% of the respondents achieved an A in the course, 16.7% achieved a B, 14.6% achieved a C, 0% achieved a D, or F. 16.7% of the repsondents preferred not to say their grade.

MIP302 lab course is a microbiology laboratory course available to second and third-year STEM undergraduate students in conjunction with the MIP300 lecture course. 25% of respondents have taken the MIP302 lab course, whereas 75% of the repsondents have not as shown in *figure 8 C.* The grades of the 25% of the respondents who took MIP302 lab were analyzed as represented in *figure 8 D.* 63.3% of the repsondents achieved an A in the course, 3.3% achieved a B,0% achieved a C, D, or F. 33.3% of the respondents preferred not to say their grade.

The comparison of MIP300 lecture grades and MIP302 lab grades are represented by *figure 8 E.*

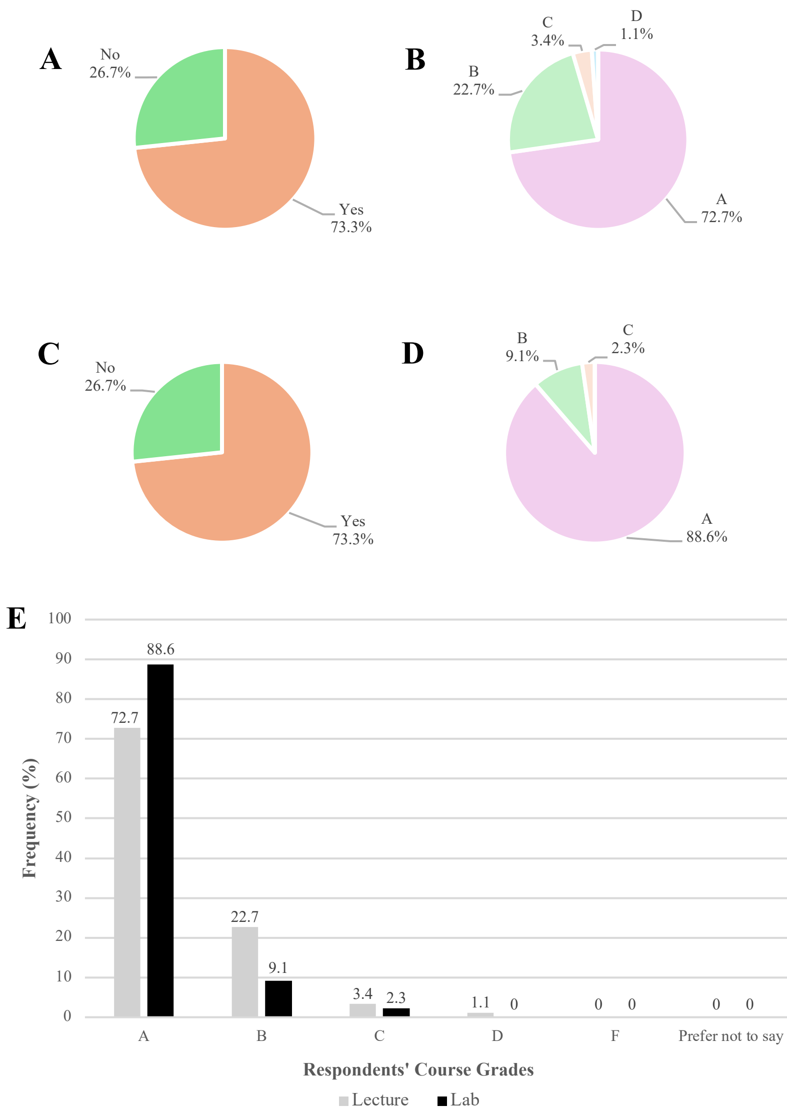


Figure 4: Life102 Lecture and Lab Courses. **A.** Distrubition of respondents' participation in Life102 lecture course. Calculated chi-squared value is < 0.05, indicating significant difference in students who have and have not participated in Life102 lecture courses. **B.** Distribution of respondents' grades in Life102 lecture courses. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Life102 lecture courses. **C.** Distrubition of respondents' participation in Life102 laboratory course. Calculated chi-squared value is < 0.05, indicating significant difference in students who have and have not participated in Life102 lab courses. **D.** Distribution of respondents' grades in Life102 laboratory courses. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Life102 lab courses. **E.** Comparison of Life102 lecture and laboratory grades. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Life102 lab courses compared to Life102 lecture courses.

For the letter grade A, there is a 11.3% difference, with more As achieved in the lab course. For the letter grade B, there is a 13.4% difference. For the letter grade C, there is a 14.6% difference, with more Cs achieved in the lecture course. For the letter grade D and F there is no difference between the lecture and lab course. There is a difference of 16.6% of the respondents preferred not to say their grade, with the majority being in the lab course.

Chem341 lecture course is an organic chemistry course available to third and fourth year STEM undergraduate students. 45.8% of respondents have taken the Chem341 lecture course, whereas 65.8% of the repsondents have not, as shown in *figure 9 A.* The grades of the 45.8% of the respondents who took Chem341 lecture were

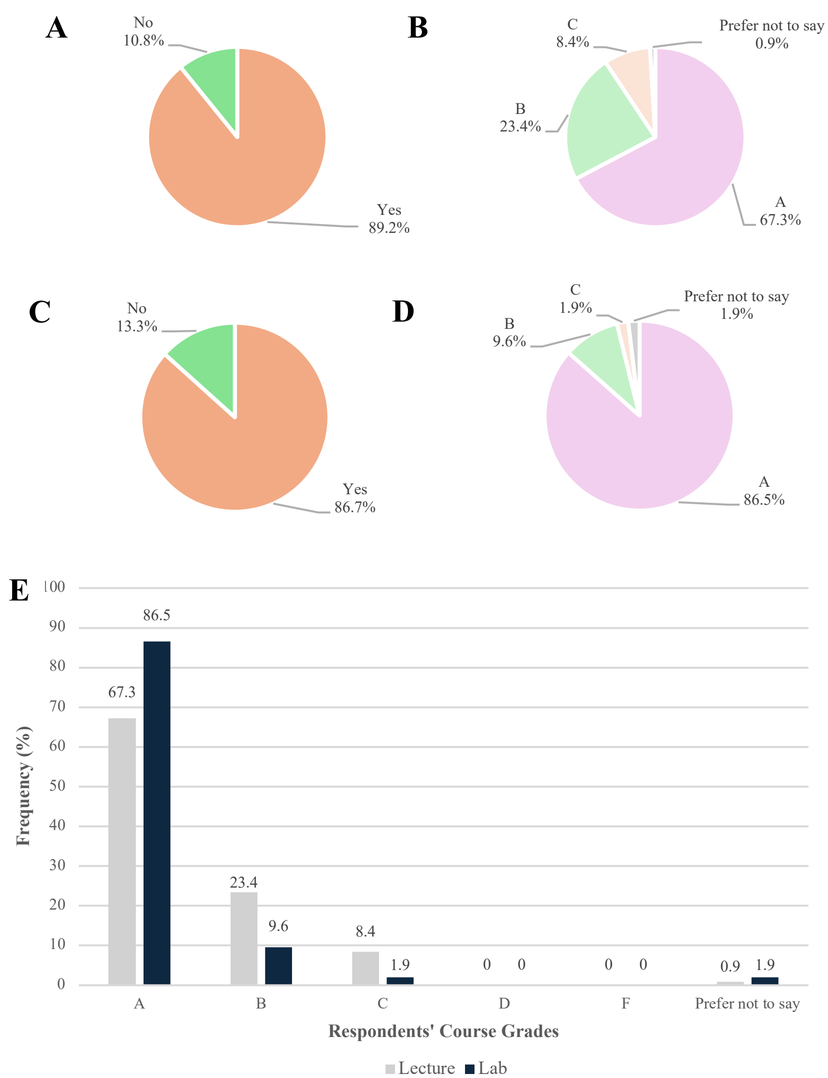


Figure 5: Chem111 Lecture and Chem112 Lab Courses. **A.** Distrubition of respondents' participation in Chem111 lecture course. Calculated chi-squared value is < 0.05, indicating significant difference in students who have and have not participated in Chem111 lecture courses. **B.** Distribution of respondents' grades in Chem111 lecture courses. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Chem111 lecture courses. **C.** Distrubition of respondents' participation in Chem112 laboratory course. Calculated chi-squared value is < 0.05, indicating significant difference in students who have and have not participated in Chem112 lab courses. **D.** Distribution of respondents' grades in Chem112 laboratory courses. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Chem112 lab courses. **E.** Comparison of Chem111 lecture and Chem112 laboratory grades. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Chem112 lab courses compared to Chem111 lecture courses.

analyzed as represented in *figure 9 B.* 58.2% of the respondents achieved an A in the course, 20% achieved a B, 12.7% achieved a C, 1.8% achieved a D, and 0% achieved an F. 7.3% of the repsondents preferred not to say their grade.

Chem343 lecture course is a contingent organic chemistry course of Chem341 and is available to third and fourth year STEM undergraduate students. 34.2% of respondents have taken the Chem343 lecture course, whereas 65.8% of the repsondents have not, as shown in *figure 9 C.* The grades of the 34.2% of the respondents who took Chem343 lecture were analyzed as represented in *figure 9 D.* 58.5% of the respondents achieved an A in the course, 26.8%

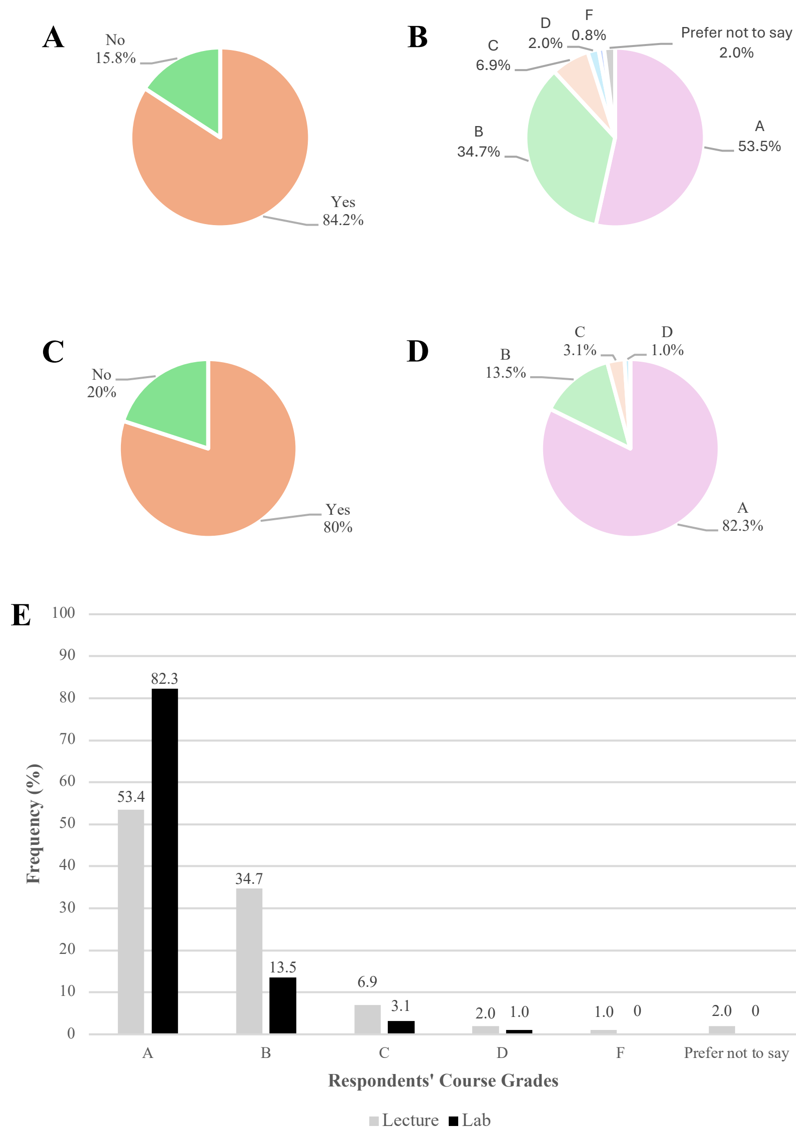


Figure 6: Chem113 Lecture and Chem114 Lab Courses. **A.** Distrubition of respondents' participation in Chem113 lecture course. Calculated chi-squared value is < 0.05, indicating significant difference in students who have and have not participated in Chem113 lecture courses. **B.** Distribution of respondents' grades in Chem113 lecture courses. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Chem113 lecture courses. **C.** Distrubition of respondents' participation in Chem114 laboratory course. Calculated chi-squared value is < 0.05, indicating significant difference in students who have and have not participated in Chem114 lab courses. **D.** Distribution of respondents' grades in Chem114 laboratory courses. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Chem114 lab courses. **E.** Comparison of Chem113 lecture and Chem114 laboratory grades. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Chem114 lab courses compared to Chem113 lecture courses.

achieved a B, 14.6 % achieved a C, 0% achieved a D, F or preferred not to say their grade.

Chem344 lab course is an organic chemistry laboratory course available to third and fourth year STEM undergraduate students in conjunction with the Chem343 lecture course. 30.8% of respondents have taken the Chem344 lab course, whereas 69.2% of the repsondents have not as shown in *figure 9 E*. The grades of the 30.8% of the respondents who took Chem344 lab were analyzed as represented in *figure 7 F.*

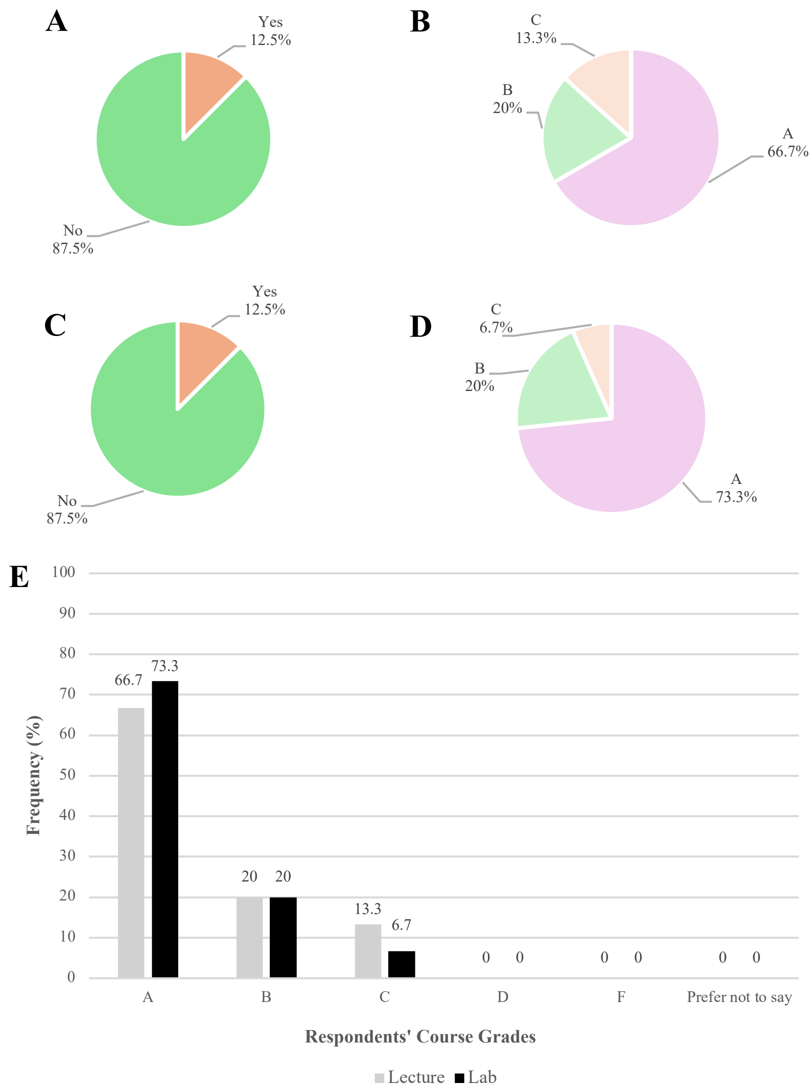


Figure 7: Life201B Lecture and Lab Courses. **A.** Distrubition of respondents' participation in Life201B lecture course. Calculated chi-squared value is < 0.05, indicating significant difference in students who have and have not participated in Life201B lecture courses. **B.** Distribution of respondents' grades in Life201B lecture courses. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Life201B lecture courses. **C.** Distrubition of respondents' participation in Life201B laboratory course. Calculated chi-squared value is < 0.05, indicating significant difference in students who have and have not participated in Life201B lab courses. **D.** Distribution of respondents' grades in Life201B laboratory courses. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Life201B lab courses. **E.** Comparison of Life201B lecture and laboratory grades. Calculated chi-squared value is 0.3 0.3< 0.05, indicating no significant difference the achieved grades of students in Life201B lab courses compared to Life201B lecture courses.

86.5% of the repsondents achieved an A in the course, 13.5% achieved a B, 0% achieved a C, D, F, or preffered not to say their grade.

The comparison of Chem341 and Chem343 lecture grades and Chem344 lab grades is represented by *figure 9 G.* For the letter grade A, there is a 0.3% difference, between Chem341 and Chem 343 lecture, with more As achieved in the Chem343 lecture course. There is a 28.3% difference between Chem341 lecture and Chem344 lab course, with more As achieved in the lab course. There is a 28% difference between Chem343 lecture and Chem344 lab

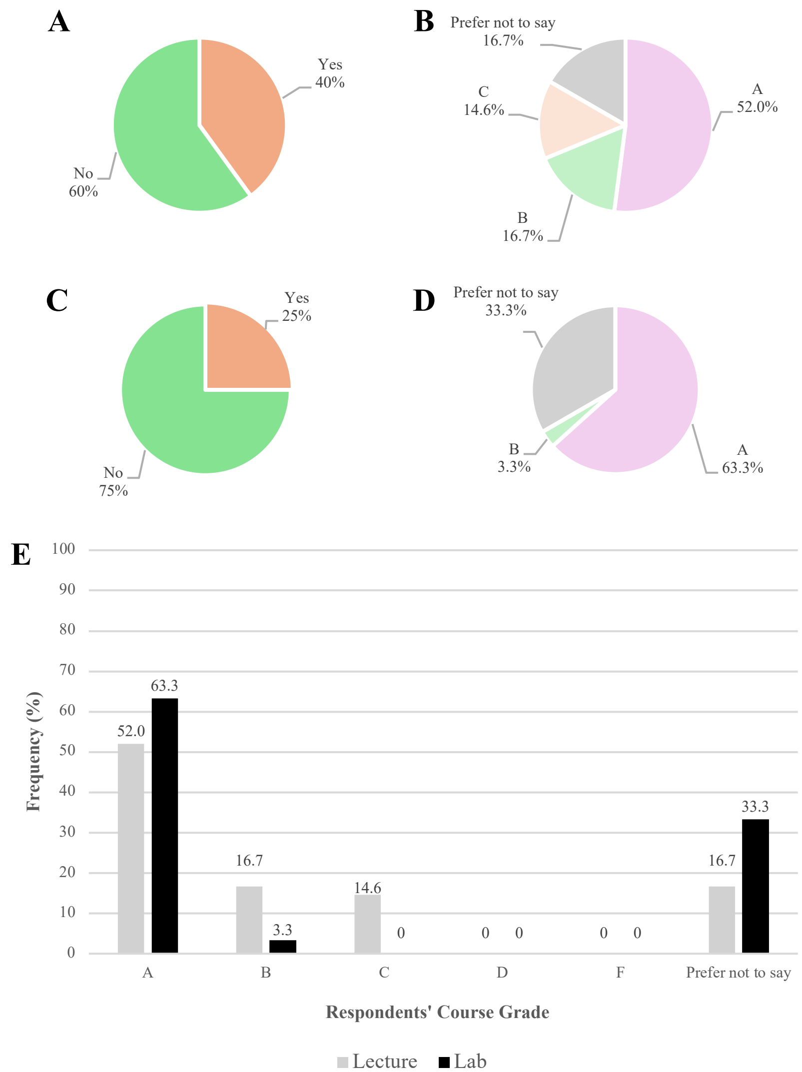


Figure 8: MIP300 Lecture and MIP302 Lab Courses. **A.** Distrubition of respondents' participation in MIP300 lecture course. Calculated chi-squared value is < 0.05, indicating significant difference in students who have and have not participated in MIP300 lecture courses. **B.** Distribution of respondents' grades in MIP300 lecture courses. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in MIP300 lecture courses. **C.** Distrubition of respondents' participation in MIP302 laboratory course. Calculated chi-squared value is < 0.05, indicating significant difference in students who have and have not participated in MIP302 lab courses. **D.** Distribution of respondents' grades in MIP302 laboratory courses. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in MIP302 lab courses. **E.** Comparison of MIP300 lecture and MIP302 laboratory grades. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in MIP302 lab courses compared to MIP300 lecture courses.

course, with more As achieved in the lab course. course. For the letter grade B, there is a 6.8% difference, between Chem341 and Chem 343 lecture, with more Bs achieved in the Chem343 lecture course. There is a 6.5% difference between Chem341 lecture and Chem344 lab course, with more As achieved in the lecture course. There is a 13.3% difference between Chem343 lecture and Chem344 lab course, with more As achieved in the lecture course. For the letter grade C, there is a 1.9% difference, between Chem341 and Chem 343 lecture, with more Cs achieved in the Chem343 lecture course. There is a 12.7% difference between Chem341 lecture and Chem344 lab course, with more Cs achieved in the lecture course. There is a 14.6% difference between Chem343 lecture and Chem344 lab course, with more Cs achieved in the lecture course. For the letter grade D, there is a 1.8% difference, between Chem341 and

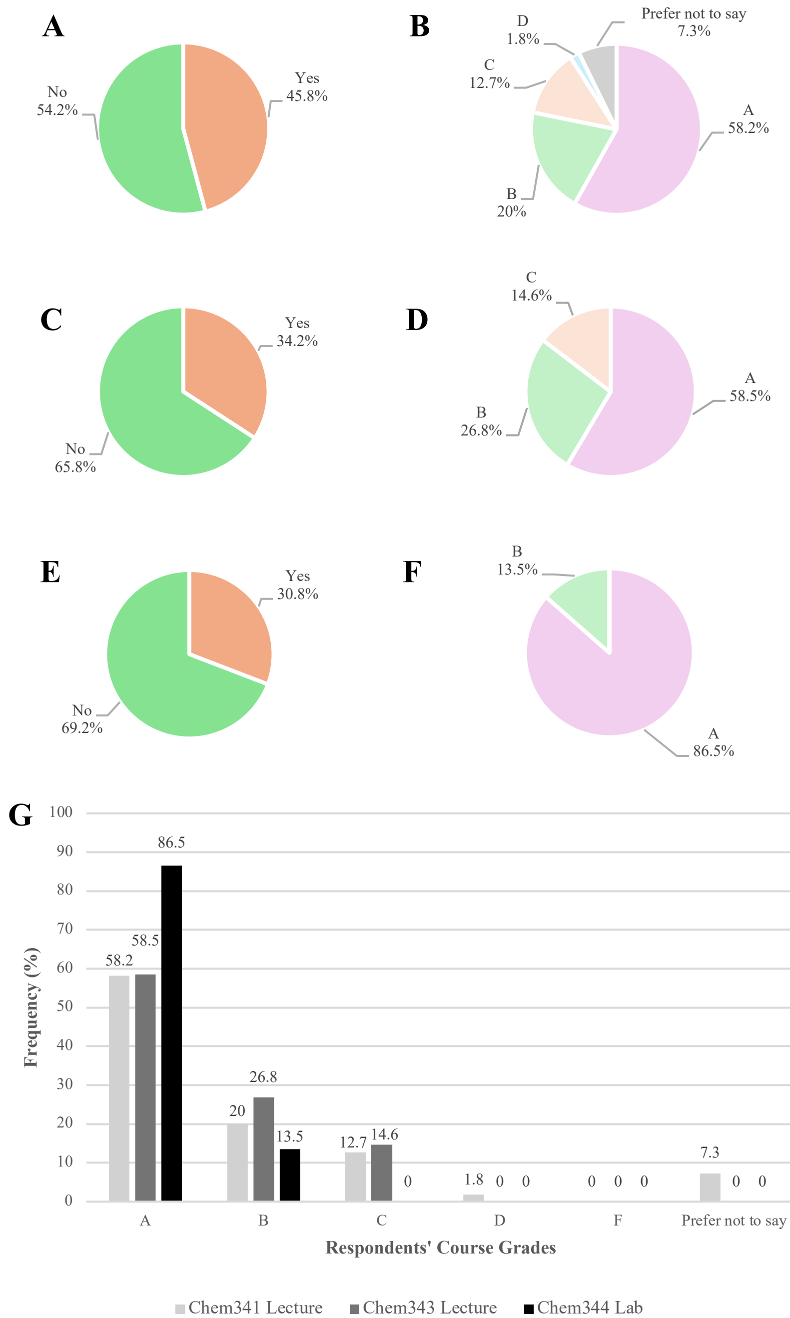


Figure 9: Chem341 and Chem 343 Lecture and Chem344 Lab Courses. **A.** Distrubition of respondents' participation in Chem341 lecture course. Calculated chi-squared value is 0.4. 0.4< 0.05, indicating no significant difference in students who have and have not participated in Chem341 lecture courses. **B.** Distribution of respondents' grades in 341 lecture courses. Calculated chi-squared value is < 0.05, indicating significant difference the achieved grades of students in Chem341 lecture courses. **C.** Distrubition of respondents' participation in Chem343 lecture course. Calculated chi-squared value is < 0.05, indicating significant difference in students who have and have not participated in Chem343 lecture courses. **D.** Distribution of respondents' grades in 343 lecture courses. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Chem343 lecture courses. **E.** Distrubition of respondents' participation in Chem344 laboratory course. Calculated

chi-squared value is < 0.05, indicating significant difference in students who have and have not participated in Chem344 lab courses. **F.** Distribution of respondents' grades in Chem344 laboratory courses. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Chem344 lab courses. **G.** Comparison of Chem341 and Chem343 lecture and Chem344 laboratory grades. Calculated chi-squared value is < 0.05, indicating significant difference in the achieved grades of students in Chem344 lab courses compared to Chem341 and Chem343 lecture courses.

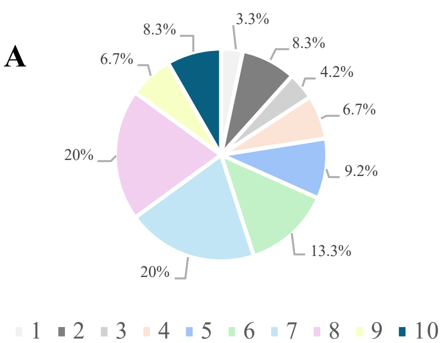
Chem 343 lecture, with more Ds achieved in the Chem341 lecture course. There is a 1.8% difference between Chem341 lecture and Chem344 lab course, with more Ds achieved in the lecture course. There is no difference between Chem343 lecture and Chem344 lab course. For the letter grade F, there is no difference between neither the Chem341 and Chem343 lecture, nor the Chem341 lecture and Chem344 lab course, or the Chem343 lecture and Chem344 lab course. For the students who preffered not to say their grade, there is a 7.3% difference, between Chem341 and Chem 343 lecture, with all respondents in the Chem341 lecture course. There is a 7.3% difference between Chem341 lecture and Chem344 lab course, with all respondents in the Chem341 lecture course. There is a no difference between between Chem343 lecture and Chem344 lab course.

Students who participated in STEM lab courses at CSU were asked to identify how helpful the lab courses were in relation to the coordinating lecture courses. The scaled data was identified by 1 signifying the lab courses were not helplful at all, up to 10 signififying the lab courses were very helpful. The data is represented in *figure 10 A*. 3.3% of respondents consider the lab courses a level 1, or not helpful at all. 4% of respondents consider the lab courses a level 2, or very poorly helpful. 5% of respondents consider the lab courses a level 3, or poorly helpful. 7% of respondents consider the lab courses a level 4, or fairly helpful. 9% of respondents consider the lab courses a level 5, or moderatley unhelpful. 11% of respondents consider the lab courses a level 6, or somewhat helpful. 13% of respondents consider the lab courses a level 7, or moderately helpful. 15% of respondents consider the lab courses a level 8, or fairly helpful. 16% of respondents consider the lab courses a level 9, or helpful.18% of respondents consider the lab courses a level 10, or very helpful.

The significance of these results suggests that there is a difference at the level of the respondents, in which the lab course is found helpful to the lecture course.

The scaled data was then split in half as represented in *figure 10 B*. The 1 to 5 data values, signifying the unhelpfulness of the lab courses in relation to the lecture courses were pooled together. The 6-10 data values, signifying the helpfulness of the lab courses in relation to the lectures courses were pooled together. The significance of this results identify that there is an impact of the lab courses on the adjacent lecture course.

A



B

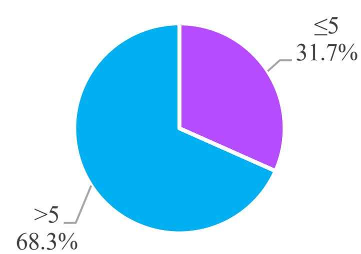


Figure 10: Benefit of Lab Courses. **A.** Distribution of respondents' asnwers to the question "For the lab courses you took, did you find a benefit to the lab section of the course?" 1 = Not helpful at all , 10 = Very helpful. Calculated chi-squared value is 0.0002. 0.0002 < 0.05, indicating significant differences on impact, at the repsondent level, the lab course has in relation to the lecture course information. **B.** Composite benefits of lab courses. ≤5 is the composite of 1,2,3,4 and 5 scores,

indicating the unhelpulness of the lab courses. >5 is the composite fo 6,7,8,9,10 scores, indicating the helpfulness of the lab courses. Calculated chi-squared value is 0.0002. 0.0002 < 0.05, indicating overal there is a significant impact the lab course in relation to the lecture course information.

Undergraduate Research

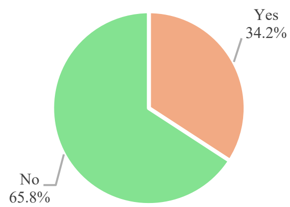


Figure 11: Undergraduate Students Engaged in Research. Distrubition of respondents' involvement in undergraduate research. Calculated chi-squared value is 0.002. 0.002 < 0.05, indicating overal there is a significant difference in students engaged in undergraduate research compared to those not engaged.

The respondents were asked to identify whether or not they are actively engaged in undergarduate research, as shown in *figure 11*. 34.2% of respondents are actively engaged whereas 65.8% of respondents are not engaged in undergraduate research. The significance of these results indicate there are less students in STEM courses enaged in research.

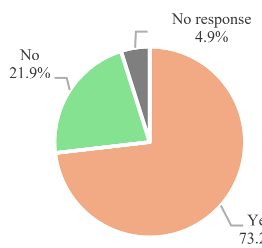


Figure 12: Topic Clairty in Conjunction with Undergraduate Research. Distribution of respondents' asnwers to the question "Does your laboratory work, outside of classes, bring clarity to any topics taught in either a teaching lab or a lecture class?" Calculated chi-squared value is < 0.05, indicating significant impact on undergraduate research bringing clarity to lecture and lab based courses.

The group of 34.2% of students engaged in undergraduate research, were asked to identify whether this experience brought clarity to their STEM lecture and laboratory courses, as shown in *figure 12*. 73.2% of the respondents said yes, their experience brought clarity to their coursework, 21.9% said no, and 4.9% provided no response. The significance of these results suggests that there is an impact on undergraduate research in relation to STEM based coursework.

CUREs Courses

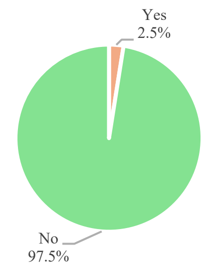


Figure 13: Distrubition of respondents' participation in CUREs course. Calculated chi-squared value is < 0.05, indicating a significant difference in students who have and have not participated in CUREs courses.

The respondents were asked to identify whether or not they particpated in a CUREs. 2.5% of the repsondents have participated in a CUREs course whereas 97.5% of the repsondents have not, as shown in *figure 13*. The significance of these results indicate there are few students in STEM courses participating in CUREs courses at the time of data collection.

Discussion

The collected data provides insight into the impact of lab courses and undergraduate research on undergraduate STEM courses. The courses in question, Life102, Chem111, Chem113, MIP300, Chem341, Chem343, and Chem344 indicated a significant impact of the lecture courses when taken with the lab. At most, a difference of 28.9% in the letter grade A, 21.2% difference in Bs, 14.6% difference in Cs, 1.8% difference in Ds, and 1% difference in Fs. At least, a difference of 6.5% in letter grade As, 6.5% difference in Bs, 1.1% difference in Cs, and no differences between Ds and Fs. The only exception was the Life201B course. The difference in lecture and lab course grades for this class, resulted in non-significant results. This lack of significance could present itself by not having a large enough population to show significance to the impact of lab courses on lecture courses.

From the respondents' individual perspectives, there is a significant difference in the impact level of a lab on a lecture course. This suggests that the impact level of a lab course on a lecture is individual based. This could arise from the efforts put into the coursework by the respondent. As a whole, there is a significant impact of a lab course on a lecture course. This suggests that in their entirety, regardless of respondents' efforts in the lab, there is an impact and importance of the lab course in relation to the lecture course.

Undergraduate research was found to be impactful on STEM lecture and lab courses. While there is a limited population of students engaged in undergraduate research, they had a higher level of impact on their STEM coursework compared to that of the lab courses. The 5% difference could result in the presence of autonomy, open ended critical thinking, and more trial and error-based experience. Such experiences rely on one's knowledge, from coursework, compared to the technique-based lab courses. CUREs courses are new undergraduate research based courses being added to STEM undergraduate majors. These courses are designed to provide students with autonomy, on a research project, within the time of a semester course. This survey identified that there are significantly few undergradute students, a part of STEM at CSU, engaged in CUREs courses. This was identified by the participation of only 2.5% of the 120 respondents.

Conclusion

With this data, there is an impact on STEM courses both through lab courses and undergraduate research experiences. In most CSU courses, there was a significant impact of the lab course in relation to the lecture course. Further, it was identified that the students' academic effort and input within the courses, proved significant on the individual level.

Undergraduate research experiences brought significant educational benefit to STEM courses. However, there are few students within the 120 respondents that took advantage of these opportunities. A possible method to increase undergraduate research experience may be to include a 100-level course. In this course students could generate resumes, apply, and interview for current research labs at CSU. Through this, students who are interested in research could become involved in active research. This course could increase STEM grades, as more students can become engaged in research and translate the knowledge that they have learned across platforms.

CUREs courses provide the opportunity for students to dip their toes into a research project, similar to ones conducted in an undergraduate research experience. Currently however, there are few respondents who have participated in the course. This could have occurred as the classified CUREs course is currently a 400-level course. The participants of this course were likely graduated seniors who no longer attend CSU.

To encourage more engagement in CUREs, the course could become required. In making the CUREs course a required course, more data can be collected. Further analysis of the CUREs course impact on the academic output in STEM lecture and lab courses, could be done.

From these findings, it can be attested that both lab courses and undergraduate research, impact the academic output of STEM students at CSU. CUREs courses need to be further analyzed at CSU, to determine if they a similar impact.

For future analysis regarding this project, the survey can include more inquiries about the CURES courses. As of right now, the only classified CUREs course is a 400-level course, making the course mainly available to seniors. There are a few lab courses, such as MIP150, general microbiology lab course, and MIP355, phage and genetics lab course, that are in progress to be classified as a CUREs course.

Making these courses more available, to biomedical sciences majors, could provide more information to determine the impact of CUREs courses. Further, students could be asked about if they know of the CUREs course(s). In addition, students can be asked whether or not they are interested in taking the CUREs courses(s). Such questions will help bring an understanding about the general interest and student activity within these courses.

Another future direction includes catering this survey towards more engineering majors, such as chemical and biological or biomedical engineering. While these majors were included in the population for this survey, there were more biomedical sciences majors. With more biomedical sciences majors, the trend for the engineering courses could have been underrepresented and therefore the trend could be different. Through incorporating the engineering lecture and corresponding lab courses, and internship opportunities, the impact of lab and real-life experiences on lecture course material can be analyzed.

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