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Investigating the Affective Domain of Chemical Education: Evaluating the Efficacy of Traditional Lectures in General Chemistry Courses at the University of Wyoming

Introduction

> "At times I would be encouraged by a little unhoped-for success, at others I would be in the deepest despair because of accidents and failures resulting from my inexperience. I was taught that the way of progress was neither swift nor easy."

As quoted my Marie Curie in her biography published in 1937, Curie highlights the difficulties in science and chemical research. People devote their lives to single concepts in their field, sometimes hopelessly devoted to their research, unsure if their findings will even be significant. While people devote their lives to science, others devote their lives to teaching science. Moreover, higher education combines the two—most times not by choice—usually creating a dilemma in professors. The internal debate between a scientist's research and teaching the next generation of scientists usually requires a few sacrifices.

Chemistry is typically a course that college students dread taking. Its combination of mathematical foundations and understandings of concepts that cannot be seen by the naked eye create a course with one of the highest drop/withdrawal rates in any university [1]. One of the other topics of discussion in chemical education comes from the dissonance between student engagement and traditional lecturing values. Where does this dissonance come from, and how can we address it moving forward?

In this research project, I sampled general chemistry lectures at the University of Wyoming (UW), and students were able to answer questions in regards to lecture engagement.

The survey aims to highlight student opinions on the effectiveness of student learning and engagement via traditional lecturing methods at UW.

Procedure

The survey was designed by adopting and adapting existing surveys (all published in the American Chemical Society Journal of Chemical Education) that were used to explore student engagement [2,3]. Surveys were be administered using Qualtrics and participants received the link via an announcement in their respective WyoCourses course page. Participant responses were downloaded from Qualtrics and stored as anonymous responses that could not be traced back to the user. No identifying information was collected on the survey and responses were analyzed and shared only in aggregate.

Survey participants are those who volunteer to take the survey and are enrolled in a general chemistry course for the spring 2025 semester. Any participants under the age of 18 were to be excluded from the survey study. Participants were selected based on their participation in general chemistry courses at UW during the spring 2025 semester. Within an announcement that would be distributed across all general chemistry sections of CHEM 1000, CHEM 1020, and CHEM 1030, participants followed the secure link to the Qualtrics survey. Participants in the survey were further determined by their voluntary deciding to follow the link and take the survey, and to check the informed consent and take the survey. The survey is all multiple-choice falling on a Likert scale. Within the informed consent, participants are informed that they do not have to answer any question they do not want, especially ones that cause negative emotions. The risk of participants being identified from this study is extremely low, as there are no self-identifying questions in the survey.

Questions:

The following topics were investigated through a series of questions based on a Likert scale:

1. course engagement and motivation
2. perceived learning and confidence in their problem-solving ability
3. the influence of instructors and their teaching methods
4. student's future intentions in chemistry

Results

For the survey, 94 individuals completed the survey and were included in the aggregate data set. After data collection, the count of participants from each section was identified and shown in table 1:

Table 1. Survey Participation Rates by Course and Section

Course	Section	Number of participants	Participation rate[1]
General chemistry I (CHEM 1020)	01 – Bandy	11	9%
	02 – Dutta	3	4%
General chemistry II (CHEM 1030)	01 – Zhou	20	24%
	02 – Hulley	53	52%
	03 – Hill	7	18%

It is noted that the average participation rate of general chemistry II students is significantly higher than that of general chemistry I sections. Additionally, the survey was sent out to the CHEM 1000 section, but there was no response from the professor, and no participants were collected from this section.

Upon data collection, the Likert scale awarded specific points for each answer—1 for strongly disagree, 2 for disagree, so on and so forth, up to 7 points for strongly agree. The null

[1] The participation rate was found by dividing the number of participants by the enrollment total in that section as seen in the registration directory. This does not correct for students that have withdrawn from the course.

hypothesis (H_0) assumes that there is no true opinion on the question at stake—which would correlate to an average of neutral—or a value of 4 on the Likert scale. Comparing the average of the participants to the null hypothesis generates a p-value using a one-tailed t-test, in which a significance level of $\alpha = 0.05$ is used (95% confidence). Due to the high number of options in the survey (7), we can assume that the distribution can be transformed from a discrete distribution to a continuous distribution. The addition of more options would have made the choices to complex and difficult for participants to select the choice that most closely aligns with their own thoughts [4].

In tandem to the t-test being used, a Cohen's d-value is also used to evaluate a skew or shift of the distribution in comparison to the null hypothesis. A d-value may be both positive or negative, indicating a positive or negative deviation, respectively. An interpretation of d-values is shown below:

Table 2. Interpretation of Cohen's d-values

d-value (abs)	0 – 0.2	0.2 – 0.5	0.5 – 0.8	> 0.8
interpretation	small shift	mild shift	medium shift	large shift

By using both a significance test and a Cohen's d-test, the distribution can both identify a statistically different opinion compared to the null hypothesis, as well as an identification of a positive or negative shift in the distribution.

Course engagement and motivation

The following questions were asked to evaluate the course engagement and motivation from the participants:

Table 3. Aggregate data collection for course engagement and motivation

question	average	standard deviation	p-value	Cohen's d-value
1. I regularly attended general chemistry lectures/labs because I found them valuable.	5.36	1.85	$\mathbf{8 \times 10^{-10}}$	0.74
2. I actively participated in class discussions or problem-solving sessions.	4.80	2.04	$\mathbf{4 \times 10^{-4}}$	0.39
3. The course materials were engaging and helpful.	4.34	1.73	0.07	0.20
4. I felt motivated to study general chemistry outside of class.	4.28	2.26	0.3	0.12
5. The course workload was manageable alongside my other responsibilities.	5.60	1.57	$\mathbf{5 \times 10^{-15}}$	1.02

From table 3, we can say with confidence that the participants feel like they regularly attend lectures, participate frequently, and manage their coursework well. However, we fail to reject the hypothesis that participants feel neutral about the engagement of the course materials and their motivation to study outside of class. While students feel like they are actively participating in class discussions, there is only a mild shift of the dataset ($d = 0.39$).

Perceived learning and problem-solving ability

The following questions were asked to evaluate the perceived learning and confidence in the problem-solving ability from the participants:

Table 4. Aggregate data collection for perceived learning and problem-solving ability

question	average	standard deviation	p-value	Cohen's d-value
6. I feel confident in my ability to solve general chemistry problems.	4.99	1.81	$\mathbf{2 \times 10^{-6}}$	0.55
7. I understood the key concepts taught in this course.	4.99	1.78	$\mathbf{1 \times 10^{-6}}$	0.56
8. I struggled with applying chemistry concepts to real-world problems.	4.45	1.78	$\mathbf{2 \times 10^{-2}}$	0.25
9. I believe I improved my critical thinking skills in this course.	4.56	1.86	$\mathbf{5 \times 10^{-3}}$	0.30
10. I often felt lost or confused during lectures.	5.01	1.92	$\mathbf{4 \times 10^{-6}}$	0.53
11. When solving problems, I can understand what is happening conceptually.	4.76	1.53	$\mathbf{9 \times 10^{-6}}$	0.50

From table 4, we can say with confidence that the participants are confident in their ability to solve general chemistry problems, and that participants understand key concepts taught in this course. Moreover, participants agree that their critical thinking skills have improved over the span of the course, and that participants can understand questions at a conceptual level.

While the above statements might indicate that the traditional lecture format is convenient and effective, we can also say with very high confidence that participants often feel lost or confused during lectures ($p = 0.00004$, $d = 0.53$). Additionally, participants struggle with applying chemistry to real-world problems ($p = 0.02$, $d = 0.25$) to a lesser extent. Table 4 highlights a key dissonance usually seen in most general chemistry lectures: students feel like they understand what is happening at a conceptual, molecular level—but fail to understand what is going on in lecture, and how the content being taught applies to the real world. If chemistry makes up our entire existence, students should be able to connect key concepts to real-world applications. It has been proven that classroom environments with most connections and relevancy to real-world applications increase student engagement and comprehension [5,6].

While this poses a potential solution to this dissonance, further studies must be conducted to extrapolate the data to the student population at UW.

The influence of instructors and their teaching methods

The following questions were asked to evaluate the influence of instructors and their teaching methods from the participants:

Table 5. Aggregate data collection for influence of instructors and teaching methods

question	average	standard deviation	p-value	Cohen's d-value
12. The instructor encouraged student questions and participation.	5.16	1.77	$\mathbf{2 \times 10^{-8}}$	0.65
13. I felt engaged during lectures.	4.30	2.00	0.2	0.15
14. The instructor seemed approachable and willing to help students.	5.39	1.80	$\mathbf{1 \times 10^{-10}}$	0.77
15. My TA was helpful during lab and/or office hours.	6.12	1.50	$\mathbf{5 \times 10^{-23}}$	1.41
16. My SI leader (if applicable) was helpful during sessions and office hours.	5.69	1.43	$\mathbf{3 \times 10^{-13}}$	1.18
17. The lab portion of the course paired well with the content discussed in lecture.	5.11	1.86	$\mathbf{2 \times 10^{-7}}$	0.60

From table 5, we can say with confidence that participants believe instructors are encouraging student participation, and that instructors were approachable and willing to help students. However, we fail to reject the null hypothesis that students do not agree or disagree with feeling engaged during lectures ($p = 0.2$, $d = 0.15$). While the data is ever so slightly skewed positive (towards the agree side), this dissonance is usually the causation of content comprehension, as previous studies have shown that increasing the engagement of a lecture leads to higher retention rates [7].

While people are lost during the lecture component of the course, we can say with confidence that TA's and SI leaders are a helpful resource throughout the semester. However—

from my observation as both a TA and an SI leader—I find that very little students utilize SI, and even less students utilize office hours as a resource.

Student's future intentions in chemistry

The following questions were asked to evaluate the future intentions in chemistry from the participants:

Table 6. Aggregate data collection for student future intentions in chemistry

question	average	standard deviation	p-value	Cohen's d-value
18. This course increased my interest in continuing chemistry or related fields.	3.78	1.99	0.3	-0.11
19. I would recommend this instructor/course to other students.	4.47	2.07	**0.03**	0.23
20. Because of this course, I feel more prepared for future chemistry classes.	4.13	2.01	0.6	0.06
21. I considered dropping this course at any point.	2.81	2.14	$\mathbf{9 \times 10^{-7}}$	-0.55

From table 6, we can confidently assume that participants are not likely to drop their current course, and that participants are likely to recommend their respective instructor or course to other students. While students are staying in general chemistry courses, participants did not agree that they are more interested in the chemical field. Additionally, participants are neutral in the aspect that their course further prepared them for future chemistry classes.

Discussion

While many of the questions led into the direction that instructors are teaching effectively, a discussion of the demographics of participants must be explored. For context, the fail rate of general chemistry II students by semester is shown below:

Table 7. Fail rates of chemistry II courses by semester

Term	Fail rate	Term	Fail rate
Fall 2024	29%	Spring 2024	6%
Fall 2023	10%	Spring 2023	14%
Fall 2022	17%	Spring 2022	10%
Fall 2021	21%	Spring 2021	8%
average	19%	average	9%

It is noted that the fail rate of CHEM 1030 sections is significantly higher in the fall term than in the spring term (n = 1420, p = 0.000004). In fact, the fail rate is more than twice as high in the fall semester than the spring semester. Since 85 percent of survey participants were enrolled in a CHEM 1030 section—and not a CHEM 1020 or 100 section—most participants were general chemistry II students who were going to pass. Additionally, the survey was administered 2 weeks after the course withdraw deadline, indicating that students who had to withdraw from the course were excluded from the survey. The scope of the survey is diminished by the lack of participation from students in CHEM 1000 and 1020. It must be noted that the outcome of the survey itself is merely representative of the spring 2025 CHEM 1030 sections. Because of reasons outlined above, we are finding statistically significant results that could indicate that students are doing well in a traditional lecture style.

The results outlined in tables 3-6 indicate that the participants struggle with understanding what is occurring in lecture, and there is sufficient evidence to believe that participants are not confident or prepared in their future chemistry courses. Extrapolating this to the demographics of general chemistry I students, it is almost certain that the results of this survey would trend to a consensus that students are not learning effectively via a traditional lecture method.

Potential improvements

While the survey had a relatively high number of participants (n = 94), there are some potential improvements that would make the survey more significant. The first source of improvement would be to administer the survey before the withdraw date, as the students who withdrew from the course were not able to participate in the survey. They hold a unique perspective that is not represented in the survey—and as a result, the findings cannot be extrapolated to that population.

The second source of improvement would be increasing student participation. From table 1, there are three sections of general chemistry courses in which less than 20% of the students completed the survey. Moreover, two sections had less than 10% participation. A source of this dissonance lies within student engagement. As the survey was administered during the last week of classes, students might not have the time to complete the survey. Additionally, sharing the survey was quite difficult, as each professor had to be contacted to deliver the survey link to the students in their course. While some professors were very involved in this process, multiple professors did not pass along the survey link, or even respond to emails outlining the process. The solution to this is more difficult. Participants did not feel like they were engaged during lecture, and this apathy could carry over to participating in external surveys. Self-selection bias is introduced, as this survey is voluntary. This indicates that students might be more compelled to respond to the survey if they feel their opinion is less neutral. However, the scope of the self-selection bias must be explored more carefully and profoundly.

Finally, the survey is cross-sectional and not longitudinal. As outlined above, most of the participants are in sections of chemistry that have a very low fail rate in the spring. If the survey was administered over the course of more than two semesters, students who are in a course with a higher fail rate will be able to provide feedback as well. This could very well change the influence of the study. Additionally, the survey does not compare sections that have a traditional lecture style to alternative methods. We cannot say that the results of this study show that active learning is more effective—we can only say that the participants felt like the current lecture style is making students confused and seek external resources.

Conclusion

The survey aims to highlight student opinions on the effectiveness of student learning and engagement via traditional lecturing methods at UW. Participants were assessed using 21 questions that are all answered on a Likert scale. Out of the 94 recorded participants, 85% of the participants were from a CHEM 1030 section, and 15% of the participants were from a CHEM 1020 section. No CHEM 1000 participants were identified or recorded. Additionally, there was a significantly higher participation rate among CHEM 1030 students in comparison to CHEM 1020 students.

While students report high levels of confidence in problem-solving and conceptual understanding, they also feel lost or confused during lectures and struggle to connect course material to real-world applications. This implies that the traditional lecturing method might not be as effective as perceived. Moreover, students value instructor approachability, TA support, and supplemental instruction (SI)—reinforcing the value of accessible academic resources. However, the lack of engagement during lectures—in tandem with neutral attitudes toward future chemistry interest—indicates room for lecturing improvement.

The survey's limitations, including self-selection bias (favoring successful CHEM 1030 students) and timing (post-withdrawal deadline), likely skew results toward a more positive outlook than reality for struggling students who might not be fairly represented in. this study.

To address these challenges, future studies should utilize the following improvements:

1. Expand participation by administering surveys earlier in the semester and including withdrawn students.
2. Compare teaching methods (active learning vs. traditional lectures) to assess impacts on engagement and retention.
3. Incorporate longitudinal data across semesters, particularly in high-fail-rate courses, to better represent diverse student experiences.

Ultimately, this study highlights the need for innovative, student-centered approaches in chemical education—whether through enhanced real-world applications, interactive lecture formats, or stronger bridges between lecture and lab content. As Marie Curie's words remind us, progress in science—and science education—is neither swift nor easy, but educational introspection is paramount to student success. After all, education is for the future scientists of the world, not for the educators themselves.

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