Evaluation of Hybrid Lab Delivery in a General Chemistry Course for Pre-Engineering Students

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Abstract
In a hybrid general chemistry course at Oregon State University (OSU), student perceptions of lab activities were compared in traditional face-to-face and virtual modalities. The study was conducted in the Spring 2022 term in CH 205, a general chemistry lab course aimed at engineering students. The students alternated between virtual and traditional laboratory activities that covered equivalent content and with identical learning outcomes. Surveys were used to evaluate students' perceptions of the two lab modalities. Overall findings from 17 students indicate that students viewed both types of lab activities as positive learning experiences.

Introduction
At a table discussion at the 2016 Biennial Conference on Chemical Education, a premise was presented: Is the purpose of a general chemistry laboratory for engineering majors to expose students to the theories and practices of modern experimental chemistry and instrumentation in a contextual, student-centered learning environment? And can this be facilitated with brick-and-mortar and/or virtual laboratory activities? Eight years before this table discussion, three Oregon State University (OSU) Chemistry Faculty began developing 30 virtual laboratory activities for a full-year general chemistry curriculum to do this. Students began completing these virtual laboratory activities in 2010.

Despite concerns that virtual lab activities might impact course quality and overall learning, Nais (2019) found that a hybrid lab program group obtained higher grades and a greater understanding of the material; additionally, the development of competencies improved by 15%. Several studies further indicate there is no significant difference between learning competencies in face-to-face and hybrid courses (Enneking et al., 2019; Gulacar et al., 2013; Hawkins & Phelps, 2013; Irby et al., 2018; Nais et al., 2018; Sánchez-López et al., 2022; Zhang et al., 2020).

Several studies further indicate the use of general chemistry laboratory programs with components outside the on-campus setting offer efficiency and flexibility (Casanova & Civelli, 2006; Sánchez-López et al., 2022; Zhang et al., 2022). This efficiency and flexibility can address challenges that arise for institutions operating on a quarter system. At OSU, the Fall, Winter, and Spring quarters are ten weeks, and each has at least one mid-week holiday which disrupts weekly lab scheduling. Additionally, the first week of each term is chaotic; students add and drop classes and sections disrupting work, scoring, and groups. Implementing virtual laboratories solves these issues and offers the ability to facilitate a laboratory experience for a missed class.

A study in the Journal of Chemical Education, Atkinson (Hamilton et al., 2024) surveyed members of chemical industry companies (N = 80) about instrument use and experience that are expected when hiring new chemists. The top five instruments for both use and expected experience included Mass Spectrometry (MS), Liquid Chromatography (LC), UV–Vis Spectroscopy, Gas Chromatography (GC), and Infrared (IR) Spectroscopy. These instruments are limited, if at all available, to general chemistry laboratory students. The Department of Chemistry at OSU feels that exposing non-chemistry majors to the instrumentation utilized by chemists is valuable and can be achieved through virtual laboratories. These experiences expose students to the tools chemists use to investigate natural systems.

Study Context
The Department of Chemistry at OSU is charged with instructing general chemistry laboratory skills and concepts to over 2,000 students in dozens of students in non-chemistry majors. The expectation is that the program will meet or exceed prerequisite needs.

The Department of Chemistry developed the first online general chemistry course in 2004 and

began developing laboratories to support student learning. Several tools were used, such as presenting students with information about how a laboratory would be performed and data sets. The Chemistry department has utilized virtual laboratory activities in online courses since 2009. The motivation to implement a hybrid laboratory program in CH 205 is to give access to experimentation and instrumentation that is not available in the brick-and-mortar general chemistry laboratory. Faculty have identified the following topics for the laboratory activities: absorbance, amylase, combustion, digestion, DNA hydrolysis, electroplating, entropy, freezing point depression, GS-MS drug, iodine clock, NMR, nuclear chemistry, osmotic pressure, and vitamin C. Figure 1 shows the design of the virtual apparatus for the virtual labs. Figure 2 shows an example of one of the virtual labs.

Figure 1. The original design in 2009 of the virtual laboratory balance and operational properties

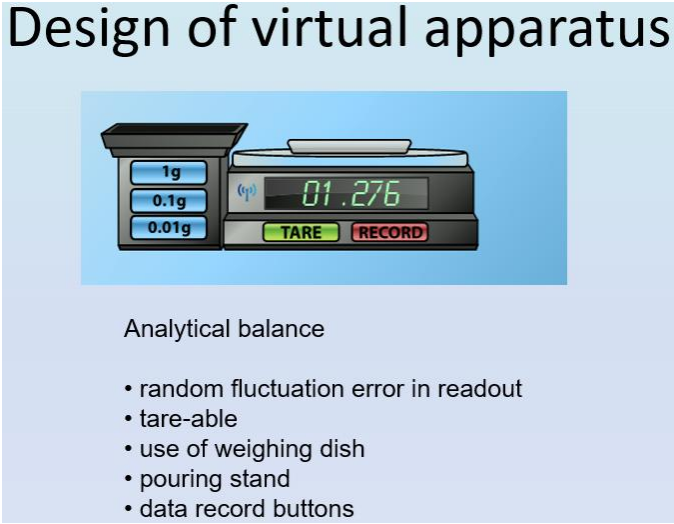
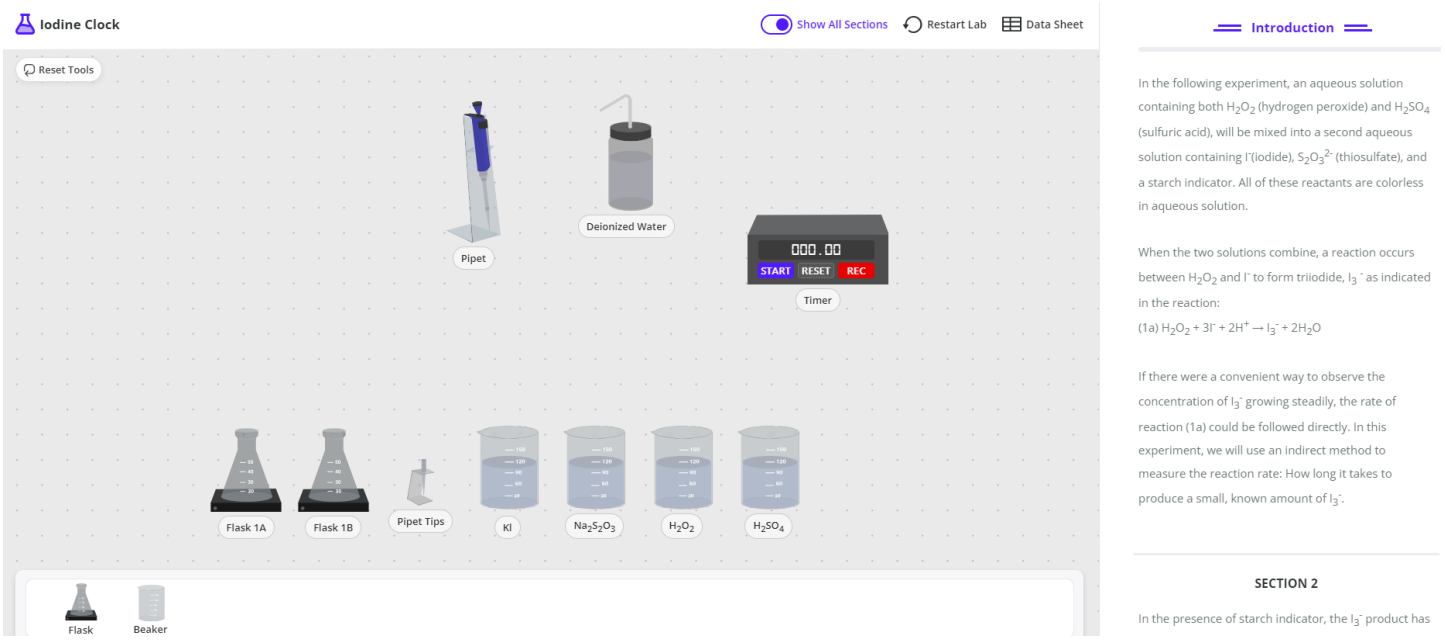


Figure 2. The Iodine Clock Virtual Laboratory



The Current Study

This study examined a hybrid version of CH 205 with of four in-person laboratory activities and five virtual laboratory activities. This study set out to investigate student perceptions of these virtual laboratory activities compared to the face-to-face laboratory activities.

Methodology

Originally scheduled to run in the Spring 2020 term, this study was postponed until the Spring 2022 term due to the COVID-19 pandemic. In the Spring of 2022, all 210 students enrolled in CH 205 participated in a hybrid laboratory program. However, only 17 of the 210 students (8%) consented and participated in this study. Four laboratories were facilitated on campus in person and five laboratories online (virtual). The laboratory activity schedule is shown in Table 1.

Table 1. Schedule of in-person and virtual laboratory activities in CH 205

Week	Laboratory Activity	
	In-Person Labs	**Virtual Labs**
1	-	Lab Techniques Linear Regression
2	Lab Check-In Copper Sulfide	-
3	-	Vitamin C
4	-	Absorbance
5	Silver Chloride	-
6	Solar Cell	-
7	-	Iodine Clock
8	The Voltaic Pile Lab Check-Out	-
9	Lab Check-Out	-
10	Holiday Week	

The four in-person laboratory meetings were facilitated in a three-hour lab period on the OSU Corvallis Campus. The five virtual labs were facilitated asynchronously without a time limit. Students were able to stop and resume the virtual lab at their convenience. The virtual labs may have been attempted multiple times without course point deductions. In-person and virtual labs had specific due dates. At the conclusion of the 10-week term, the students were asked to complete a survey. The identity of the consenting and non-consenting students was not known to the instructor of record or the researchers.

An anonymous student survey tool was used to capture student attitudes toward on-campus and virtual laboratories in this General Chemistry course. The 9-item survey is shown in Appendix A. Students were asked about their favorite and least favorite virtual lab activities. They also ranked the virtual and in-person labs and were asked to provide details about what they liked. The course instructors and facilitators of this study were not aware of which students were part of this study and which students were not, and they were not aware of laboratory scores and course grades. Participation in this study was managed by an Office Administrator who was not involved in instruction or scoring.

Results

The Student Attitude Survey data is provided in Appendix B and lab preference rankings sare provided in Appendix C. Overall, students described their favorite **virtual lab** experiences as “interesting”, “cool” and “fun.” Six of 17 students (35%) indicated the Iodine Clock Virtual Lab was their favorite lab activity of the virtual lab activities. Several students indicated it was fun and/or interesting while one student reported, “It is cool to think about why it takes a certain amount of time it takes for something to react and why.” Three of 17 students (18%) indicated the Iodine Clock Virtual Lab was their least favorite lab activity of the virtual lab activities. One student wrote of the Iodine Clock Virtual Lab:

> “I think this Lab was my least favorite because it mostly felt like it involved a lot of clicking and then waiting, but overall this lab was still pretty good. It still easily accomplished the goal of teaching the material, even if it was a bit tedious.”

Another student wrote of the Iodine Clock Virtual Lab, “Got low scores.”

Table 2 below reports students’ comments about the virtual labs and quality ratings the study team assigned to each lab based on students’ comments. Quality assignments ranged from -1 to 1, where a “1” was assigned if comment was positive, a “0” if the comment was neutral, and “-1” was assigned if the comment was negative. The sum of the quality assignments was 14 out of a total 17 possible, indicating that students’ comments were overwhelmingly positive.

Table 2. Participants’ comments about virtual labs rated for quality

Virtual Lab Comment	**Quality rating**
I thought it was interesting to see how light gets blocked by different solutions	1
It was interactive and timing the changes was fu	1
Well balanced between learning and interesting	1
I liked the colors of the liquids.	1
it felt a little more realistic, the other ones were more difficult to do online and made me feel like I didn't grasp everything just because I didn't do it in person	-1
It didn't glitch as much and was a fair and understandable lab.	1
Enjoyed the process and was generally interesting	1
Working with the spectrometer was really cool	1
This one seemed the most interesting to me. Learning about the light absorbance was also very easy through the virtual lab.	1
It was the most interesting lab.	1
I loved learning about solar panels	1
I just found this one to require the most steps making it more interesting	1
Nice to understand and do work on it.	1
I liked this lab because the materials we used were pretty cool and the actual activity is the most fun	1
It is cool to think about why it takes a certain amount of time it takes for something to react and why	1
I liked the systematic approach to how the lab was done.	1

Students similarly described their favorite **in-person** lab activities as “interesting”, “cool” and “fun.” The two favorite in-person lab activities were the Voltaic Pile and Solar Cell. Of the Solar Cell lab activity, a student wrote, “I thought it was just super cool that it was even possible to make a solar cell.” Another student wrote of the in-person Solar Cell lab activity, “Getting to build something that had a real practical application was cool, and also I liked that we got to work in a bigger group for it.”

Table 3 below reports students’ comments about the in-person labs and quality ratings the study team assigned to each lab based on students’ comments. The sum of the quality assignments was 14, identical to the virtual lab activities. This finding indicates that students’ comments were overwhelmingly positive and did not differ from students’ experiences with virtual lab activities.

Table 3. Participants' comments about in-person labs rated for quality

In-Person Lab Comment	Quality rating
It was interesting to see how these batteries could operate at such a basic level	1
It was interesting to learn how batteries were started and the reaction that takes place	1
It was really interesting how it worked.	1
Getting to build something that had a real practical application was cool, and also I liked that we got to work in a bigger group for it.	1
I thought it was just super cool that it was even possible to make a solar cell.	1
Batteries	0
I liked the open scope of this one but that is also something a I partially disliked.	0
Was really cool to make a battery	1
I really liked the Solar cell activity, it was a lot of fun and it was a pretty easy lab with steps that were easy to follow. The Voltaic pile was a close second though. Both of these labs were a very good experience for me.	1
It was the most interesting.	1
I love energy and I want to make solar panels better.	1
This was the most open ended and not as guided one so we got to mess around with different designs	1
More hands on and a much more open creativity.	1
We got to use fire and burn stuff	1
it was very interactive and cool to see how each light reacted with the solar cell.	1
It seemed the most practical out of all the labs and it was interesting	1

Discussion

Results from this study indicate that students in this general chemistry course viewed both in-person and virtual lab activities in equally positive ways. However, the hybrid program offered flexibility in scheduling and access for students. On campus, the availability of instrumentation for hundreds of lower-division students can limit access to on-campus chemistry lab experiments due to scheduling, instrumentation delicacy, safety, and meaningful data acquisition due to time constraints and training.

Faculty have also commented on the benefits of virtual laboratories regardless of the availability of comparable in-person laboratories. The benefits they cite include: 1) flexible scheduling (holidays, illness, inclement weather); 2) access to virtual equipment and instrumentation that is not available to students in an in-person scenario; and 3) higher quality data, as certain data obtained in a brick-and-mortar laboratory can be poor quality.

Note that the number of student participants in this study was small, partially due to the scheduling difficulties in 2021. Therefore, the results from this small data set cannot be generalized to other students in lab-based courses and should be considered preliminary. Nevertheless, these preliminary findings suggest that students in this general chemistry course enjoyed both virtual and in-person lab activities. This is promising, as OSU will enroll near 1,000 students in the general chemistry laboratory program, increasing the number of students by a factor of five. Offering hybrid lab activities in this program can grant students flexibility in ways that

continue to support enjoyable learning experiences.

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Appendix A. Student Attitude Survey

1. What was your favorite lab activity of the virtual lab activities?

   Why?

2. What was your LEAST favorite lab activity of the virtual lab activities?

Why?

3. On 1-5 scale, 5 being best, rank overall the set of virtual lab activities and the set of on campus lab activities.

4. Have you used other virtual chemistry labs before?
    a. Yes - If yes, please tell us what course you took.
    b. Was there something about that lab that you liked better or worse?

5. Which was your favorite on campus lab activity?

    Why?

6. Anything else you'd like to share to help us improve the virtual lab activities?

Final Grade [Entered By Program Facilitator]

7. Do you have any concerns about using virtual labs for part of your assignments?

If none, you can simply respond "none".

8. Do you consent to participate in this study?

If you provide your consent, your course outcomes and survey responses will be used to help assess the use of hybrid lab delivery.

Appendix B. Comments about favorite virtual lab activities

Favorite Lab	Comment
Absorbance	Enjoyed the process and was generally interesting
Absorbance	I thought it was interesting to see how light gets blocked by different solutions
Absorbance	This one seemed the most interesting to me. Learning about the light absorbance was also very easy through he virtual lab.
Absorbance	Working with the spectrometer was really cool
Iodine Clock	I liked this lab because the materials we used were pretty cool and the actual activity is the most fun
Iodine Clock	I loved learning about solar panels
Iodine Clock	it felt a little more realistic, the other ones were more difficult to do online and made me feel like I didn't grasp everything just because I didn't do it in person
Iodine Clock	It is cool to think about why it takes a certain amount of time it takes for something to react and why
Iodine Clock	It was interactive and timing the changes was fu
Iodine Clock	It was the most interesting lab.
Lab Techniques	It didn't glitch as much and was a fair and understandable lab.
Lab Techniques	Nice to understand and do work on it.
Vitamin C	I liked the colors of the liquids.
Vitamin C	I liked the systematic approach to how the lab was done.
Vitamin C	I just found this one to require the most steps making it more interesting
Vitamin C	Well balanced between learning and interesting

Comments about least favorite virtual lab activities

Least Favorite Lab	Comments
Absorbance	it was all math
Absorbance	The end was a little confusing to me since I didn't know how to perform one of the calculations.
Iodine Clock	I do not think that the iodine clock was a lousy lab. I wish it were an experiment we would get to do in person.
Iodine Clock	I think this Lab was my least favorite because it mostly felt like it involved a lot of clicking and then waiting, but overall this lab was still pretty good. It still. easily accomplished the goal of teaching the material, even if it was a bit tedious.
Iodine Clock	Got a low score.
Lab Techniques	It was boring.
Lab Techniques	It was so boring.
Lab Techniques	It was useful but the most boring
Lab Techniques	Generally uninteresting
Lab Techniques	Just a little less hands on and engaging but, very necessary.
Lab Techniques	Long and tedious but explains everything well
Lab Techniques	The interactive lab seemed pretty intuitive so the basics were kinda boring
Lab Techniques	This was just the most boring since I have lab experience
Linear Regression	No real reason
Linear Regression	Using the excel just hurts my brain
Vitamin C	The counting was off and it brought my grade down for dropping the solution into the flask. Needs to have an actual counter because I counted exactly 3 times the amount of drops and it still told me I was wrong.

Appendix C. Students' rank ordered preferences for virtual and in-person lab activities
(1 = lowest ranking and 5 = highest ranking)

(Virtual) Lab Techniques	(Virtual) Linear Regression	(Virtual) Vitamin C	(Virtual) Absorbance	(Virtual) Iodine Clock	(In Person) Copper Sulfide	(In Person) Silver Chloride	(In Person) Solar Cell	(In Person) Voltaic Pile
3	4	5	5	4	3	3	3	3
3	4	5	5	5	5	5	5	5
1	2	3	2	2	3	4	5	3
4	4	4	3	4	3	4	5	5
5	3	5	5	5	5	5	5	5
3	3	3	1	4	4	4	5	5
2	1	2	2	4	2	3	1	4
3	3	4	5	5	4	4	4	4
3	3	3	5	4	3	3	4	5
4	4	4	5	3	4	4	5	5
3	3	4	4	4	4	4	5	5
2	5	5	5	5	5	5	5	5
3	4	5	3	3	4	3	5	5
2	2	2	2	2	3	3	3	3
4	4	4	4	4	4	4	4	4
5	4	4	5	5	5	5	5	4
3	3	5	4	3	3	4	5	4

About the Research Unit at Oregon State Ecampus

Vision

The Ecampus Research Unit strives to be leaders in the field of online higher education research through contributing new knowledge to the field, advancing research literacy, building researcher communities and guiding national conversations around actionable research in online teaching and learning.

Mission

The Ecampus Research Unit responds to and forecasts the needs and challenges of the online education field through conducting original research; fostering strategic collaborations; and creating evidence-based resources and tools that contribute to effective online teaching, learning and program administration.

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Suggested Citation

Nafshun, R. L. & Lerner, M. M. (2025). *Evaluation of a hybrid lab delivery in a general chemistry course for pre-engineering students*. [White Paper]. Oregon State University Ecampus Research Unit.