Understanding How Students Navigate An Upper-Year Science Laboratory Course In A Post-Pandemic Era

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The scope of this preliminary study revolves around investigating the effectiveness of experiential learning in upper-year science laboratory courses in a post-pandemic era. In this study we have explored two key questions: 1. Can experiential learning facilitate independent inquiry in an upper-year undergraduate laboratory in a post-pandemic era? 2. Do incoming students feel prepared to carry out an in-person, hands-on, upper-year undergraduate laboratory experiments in a post-pandemic era? By exploring these questions through student reflections and perceptions in an advanced analytical chemistry inquiry-based laboratory course, we hope to acknowledge the impact the pandemic has had on first- and second-year foundational labs, and on the preparation of students for upper-year undergraduate labs. The shift towards virtual learning during the COVID-19 pandemic may have heavily impacted the development of core wet laboratory skills and thus made it challenging for students to build their confidence and skillset and attain success when challenged at a higher level.

Experiential Learning in Undergraduate Science Programs

Undergraduate science programs include research components which accompany lectures and tutorials to support the teaching and learning of complex topics. They also enable students to build laboratory expertise, develop critical reasoning skills and develop transferable skills (Adebsi, 2022: Petrella & Jung, 2008).

There are different ways to facilitate a laboratory course. In the case of introductory labs (usually first- and second-year labs) it is common for the instruction style to be problem-based. This style is structured and usually provides the student with a step-by-step protocol and expected results. The goal of these experiments is to help support the theoretical knowledge learned in class while also building technical and practical skills in the lab. In third and fourth year the labs start to encourage more independence and critical thinking, aimed at simulating a

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real research experience (Windschitl, 2002; Flynn & Biggs, 2011; Muna 2021; Braun & Clarke, 2013). This style of facilitation incorporates experiential learning in undergraduate science programs.

Experiential learning was introduced by Kolb in 1984, and focuses on learning through, and being evaluated on previous experiences (Kolb, 1984; Sternberg & Zhang, 2014; Kong, 2021). Many upper-year labs aim to integrate experiential learning that could be described by "Do, Reflect, and Think and Apply" (Butler et al., 2019). The learning process can be described as hands-on experience (Do), followed by reviewing the results (Reflect), interpreting the results in the context of current knowledge and literature (Think) and amending the next steps according to this reflection (Apply).

The framework of experiential learning is what upper-year level labs aim to facilitate to help students take ownership of their learning, engage with the content on a deeper level, as well as develop essential research skills through the process.

Perceived Gaps in Undergraduate Laboratory Learning During the Pandemic

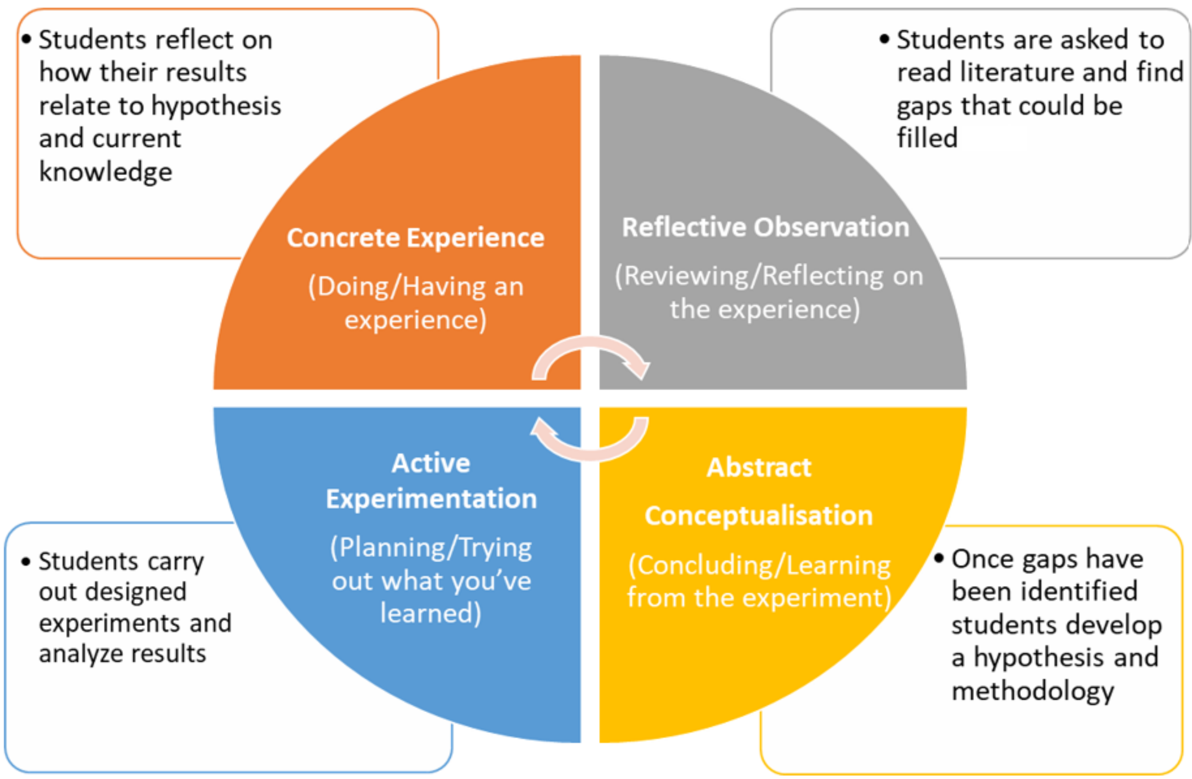
In 2022 universities across North America were in a new stage of the post-pandemic era where students entering into their third and fourth years of their programs had their previous two years of education almost completely online. In undergraduate science programs some lab components were simulated online using software but there was very minimal (in most cases none) in-person experience that could be acquired from this (Watts et al., 2022; Svatos et al., 2022). Some benefits that arose from this was the development of online components to laboratory courses, assessment of the pedagogy of labs and the opportunity to explore alternate ways of course delivery. We think that there were some perceived losses which included science undergraduate students not having the opportunity to build their lab techniques/practices. Since labs also serve to reinforce the theoretical knowledge learned in lectures there is the possibility that the loss of in person wet-labs hindered effective delivery of the course material. Now entering third or fourth year it is our hypothesis that these students are missing experience that would have better prepared them for autonomous laboratory work and experience that would have strengthened their theoretical knowledge.

The foundation years (year one and year two) are important as they allow us to facilitate experiential learning labs in upper years (year three and year four). Experiential learning, as outlined above, occurs when: the experiences are supported by reflection; critical analysis, the learner is required to take initiative and is held accountable for results; the learning is actively engaged in formulating questions and experimenting (https://www.aee.org/what-is-experiential-education, 2023). This describes most upper-year labs and in Figure 1, the steps of experiential learning are outlined generally (and specifically for this course) based on the learning cycle developed by Kolb (Braun & Clarke, 2013). The bullet points correspond to the steps carried out in the Advanced Analytical Chemistry Laboratory course.

In order for students to successfully work their way through the cycle they need a strong foundation of skills that include: lab techniques, introductory theoretical knowledge, and knowledge of scientific resources. In the absence of those first two years of lab experience it can prove challenging to students to effectively carry out the steps involved. Adapted from: https://www.aee.org/what-is-experiential-education

Figure 1

Learning cycle developed by Kolb



Advanced Analytical Chemistry Inquiry Based Laboratory (Methodology)

The advanced analytical chemistry course was created in the fall of 2021 as a new offering for students in the chemistry department. In the fall of 2022, when the course was offered a second time (with 10 students registered), it was introduced as an inquiry-based lab where students were encouraged to find a novel research question to answer throughout the semester. This is based on the experiential learning framework and the specific steps for the Advanced Analytical Lab in relation to Kolb's learning cycle as outlined in Figure 1. Students were required to conduct a literature search, find a gap, and develop a research plan to carry out throughout the semester. Students had access to multiple pieces of instrumentation and for the purpose of this lab, used multiple acid digestion techniques (microwave digestion and hot block digestion) as well as the newly installed microwave plasma atomic emission spectrometer (MP-AES) for elemental analysis of samples.

Prior to the start of the course in 2022, institutional ethics approval was obtained to conduct a study on the teaching of this course (HREB No. 103262). During the semester, this SoTL study was conducted, and students were asked to take part in reflections on their experience twice in the semester; the first reflection was conducted during week four of the lab course and the second during week nine. Due to confidentiality, it cannot be confirmed if the same set of students took part in both reflections. The reflections allowed for students to complete an open-ended question that asked students to expand on their thoughts on the structure of delivery of the lab. As this is the first time this course has been delivered this way and one of the first times the students have been asked to carry out experiential learning in a laboratory course during their degree program, we feel it was a good opportunity to understand whether they felt they had gained skills in the laboratory and to evaluate experiential learning in an upper-year lab.

Student Perspective on the COVID-19 Pandemic and its Impact on Learning

The reflections provided from the students, gave us information about how they perceived their time in an experiential learning lab, as well as provided us with insight as to how students felt about their lack of prior in-lab experience, and how it impacted their learning. We conducted an analysis to identify words that were commonly used in the reflections (keywords) and trends that arose from the comments, which are summarized in Table 1.

Three trends in particular include: Challenges during COVID-19, Confidence and Guidance and Lab Techniques (Table 1). These were most strongly noted in the first set of reflections, which were completed by 6 students from the class, at 4 weeks into the semester. Two students commented about their lack of time in the lab due to the pandemic and how that impacted their abilities going into the lab. The following comments demonstrate the trend that students felt challenges due to COVID-19 such as mixed feelings, progression as well as guidance and confidence.

> “It also didn't really help that I haven't had much lab experience prior to this course because of the pandemic and everything being online…. When I know what I am doing, being independent in the lab can be a lot of fun.”

> “...I felt a bit overwhelmed just because it's been so long since we've had a lab for the class. I took the first two analytical classes online during covid and I haven't been in the lab for 2 years, so it was a bit hard at first. Now I do feel a bit more confident….”

Table 1

Analysis of the five most frequent keywords, trends and patterns from two reflections

Reflection	Keywords	Trends and Patterns
Reflection #1 6 participants	1. Lab 2. Confidence 3. Guidance 4. Techniques 5. Learning	1. Learning and Development 2. Guidance and Confidence 3. Challenges due to Covid 4. Lab Techniques 5. Mixed Feelings and Progression
Reflection #2 7 participants	1. Lab 2. Confidence 3. Experience 4. Learning 5. Project	1. Positive Learning Experience 2. Impacts of Lab on Personal Growth 3. Application of Lab Techniques 4. Independence and Critical Thinking 5. Challenges and Suggestions for Improvement

Students also seem aware of the hurdles they have been presented due to the pandemic and know that they have lost out on a meaningful amount of time in the laboratory. As such, we believe an opportunity for them to become independent and have more autonomy over their time in the lab can be beneficial, but also may seem overwhelming, which fit into three commonly observed themes of: 1. Guidance and Confidence, 2. Learning and Development and 3. Mixed Feelings and Progression, which are supported by two students who reflect:

> "...So far the lab isn't going as well. There are many uncertainties present in this lab which makes it seem daunting and the amount of necessary information which we're not told in the lab is concerning. More guidance can be helpful towards having a positive outcome from this lab."

> "Although the lab might have seemed a bit complicated at the beginning of the semester, I feel somewhat okay with it now…The lab has pushed me to think critically."

In the second reflection, which occurred nine weeks into the semester, most of the seven students who participated commented on their growth, how they felt about the experiential learning lab course, and how they felt it could help them for future endeavors. The themes best highlighted by the student below are: 1. Independence and Critical Thinking, 2. Impacts of Lab on Personal Growth, 3. Positive Learning Experience and 4. Application of Lab Techniques.

> "My experience with the lab so far was that it was fun to an extent being able to be in charge of my own research project. However, I did feel a bit unprepared going into this lab project because I didn't have the necessary lab experience to have the confidence to conduct my own research. The majority of the class hasn't been in a lab for the subsequent courses leading up to this level due to covid for 2 years. So it was overwhelming at first. Now its a bit better to be able to apply what we learned in class and do it on our and I have felt I've grown throughout the semester regarding this project…"

Lab, confidence and learning are seen in both sets of data but it is interesting to note that *confidence* and *techniques* shift to *experience* and *project* in the second reflection. Even the themes connected with the reflection begin to shift within the few weeks between the two reflections. To highlight a few of the themes in particular, students early on were able to acknowledge how much they learnt during the semester highlighting the confidence they gained, the new skills and techniques learnt, and the application of concepts learnt within the classroom.

Future Outlook

Our initial exploration into the impact the COVID-19 pandemic has had on experiential learning in upper-year science laboratory education highlights the numerous challenges faced by the students entering an advanced analytical chemistry laboratory course. The "Do, Reflect, Think, and Apply" (Butler et al., 2019) cycle proves to be a valuable guide for experiential learning. It can be implemented by instructors in upper-year lab courses that proved worthwhile to students entering an advanced lab course after up to two years of virtual learning. The outlook for these students is positive in spite of the self-recognized loss of critical wet-lab experiences due to the pandemic.

Student reflections clearly indicate initial hurdles faced by the majority of students in the lab. Themes such as guidance and confidence, learning and development, and mixed feelings and progression highlight the factors that shape a student's experience. As the semester progressed, a positive trajectory was observed and students indicated trends associated with growth, independence, critical thinking, and personal development. It is important to note that the initial challenges were overcome with targeted and guided support, as indicated in this student comment: "I have gained invaluable lab experience and it has strengthened my ability to perform experimentation for future endeavours like grad school/professional school."

This study serves as a first step in further understanding science laboratory education in a post-pandemic environment. By acknowledging challenges and opportunities, educators can further bridge the gap between experiential learning and problem-based labs. Although limited by the study being done in a single class with 60-70% response rate, the goal will be to continue this work and further develop the questions we ask. The expansion of this study to other courses and disciplines will help us to further understand how to prepare students for life outside of the lab.

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