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Categorizing Student Learning about Research, Nature of Science, and Poster Presentation in a Workshop-Based Undergraduate Research Experience

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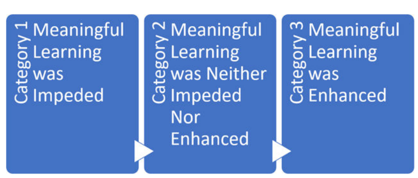
Abstract

This article examines student experiences in a workshop-based undergraduate research experience studying the activity and inhibition of salivary amylase that provides students with the chance to participate in authentic scientific research prior to the start of their undergraduate studies, following the structure of a course-based undergraduate research experience (CURE). Understanding student experiences at this point in their studies is important because research experiences at the beginning of university studies have been shown to increase retention in STEM. This study utilizes meaningful learning and situated cognition as theoretical frameworks and phenomenography as a methodological framework, applied to data from semi-structured interviews with six students. The student experiences were characterized as an outcome space detailing the degree of their meaningful learning with respect to their understanding of the research process, nature of science, and the poster creation and presentation process. The findings highlight that meaningful learning is achieved when research is connected to students' personal lives and/or future job interests. The research process and nature of science must also be made explicit to students by emphasizing the iterative nature of research and highlighting distinctions between science and non-science fields. All participating students displayed an understanding that anyone can partake in science anywhere. Implications for building on this work to develop an understanding of students' sense of belonging and self-identity are also discussed.

Graphical Abstract



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INTRODUCTION AND BACKGROUND

The issue of retention in STEM fields is a major concern because many students change their majors within the first year or two of starting their degree.[1–3] It is understood that retention in STEM increases with positive affective experiences.[4] For example, students who experience activities that connect them with the STEM community and that encourage them to go into research are more likely to express increased interest in and continue in STEM.[4,5] Often, these activities aim to have students think more like a scientist and to make their own discoveries. Some go even deeper by offering learning in a research setting, where the outcome of the activity is unknown to both students and the instructor(s).[4,6]

One important purpose for learning in a research setting is to let students learn about the research process and nature of science (NOS) outside of simple knowledge of facts and practices in science. Russell and Weaver previously investigated student understanding of NOS by comparing traditional labs, inquiry-based labs, and course-based undergraduate research experiences (CUREs) across 5 public universities. They found that only students in the research-based labs discussed experimental controls, repeatability, unknown outcomes of experiments, and mentioned how scientific practitioners engage in science during their daily work.[7] Schwartz et al. investigated the depth of nature of science understanding among 13 preservice science teachers earning a Master of Arts in Teaching. The authors found that simply having an authentic research setting is not enough for deeper understanding of the nature of science, but that it is also important for learners to actively reflect on NOS, recognize connections between aspects of NOS, and maintain a reflective perspective on NOS to further deepen and challenge one's views on the matter.[8,9]

Learning in a research setting also has the potential to support students' learning about the research process itself. In one study conducted across four liberal arts colleges, students referred to gains in critical thinking as well as analyzing data.[10] The study also found that skills in how to search for information and collaborating with others were key to the research process.[10] The role of information retrieval was also documented in library science in a comparison of the research process of first-generation college freshmen and seniors.[11] This showed the importance, for seniors, of repetition and asking for help in the search for sources, as opposed to freshmen who often viewed it as a one-time thing. Another study, from nursing, documented how the steps in the research process were taught to students in the context of integrating pharmacology and nurse-patient interactions.[12] The steps investigated in that paper were identifying a problem, reviewing the literature, developing a hypothesis, formulating research design, collecting data, analyzing data, determining results, and disseminating the findings.[12] In a study in chemistry, Kolon and Mabrouk found that a research program for undergraduates enhanced their understanding of how and why research is conducted as well as the fundamental human nature of research and the role of failure in research.[13] Searching for literature and using the appropriate databases to answer research questions has also been explored in the context of CER.[14]

Finally, communicating about science is important when results are research-based. For that reason, student presentation skills through poster sessions have gained increased attention in recent years as an assessment tool for students to demonstrate their knowledge.[15] The documented benefits of poster assessment include improving communication skills as well as the ability to work with others.[16] Students are evaluated on such categories as the layout of their poster[15], their ability to clearly describe their research topic[15] as well as use of appropriate scientific jargon[17], and their ability to correctly respond to questions after their poster presentation.[17] How such presentation experiences also may impact student retention and engagement with research has not been studied.

In this article, we examine student experiences around these three aspects of learning in a chemistry research setting: their understanding of the research process, nature of science, and their poster creation and presentation skills. We do this within the context of the UIC STEM Initiative CoLab Program, a workshop-based undergraduate research experience previously described in this *Journal*.[18] Incoming university first-year and transfer students engage in open-ended research on a chemical phenomenon, usually on one day a week for multiple weeks in the summer prior to starting at the university. More recently, a "mini-CoLab" version of this workshop has been developed that occurs over three consecutive days during the winter break. Over the course of several years, we have seen that students have very high rates of retention towards graduation and towards graduation in a STEM major.[18]

Given the unique nature of the CoLab as a place to be introduced to chemical research, and the intriguing levels of student retention, it is important to characterize more carefully the student experience in this setting. Previous work in this *Journal*[19] described student affective experiences in the context of courses offered in a university as well as course-based undergraduate research experiences (CUREs), but, to the best of our knowledge, this is the first such article describing affective experiences in a workshop-based undergraduate research experience.

THEORETICAL FRAMEWORKS

Situated Cognition

Situated cognition emphasizes how context is important in understanding and supporting learning.[20,21] This framework was a major influence on the Center for Authentic Science Practice in Education (CASPiE), an early example of a CURE and a direct precursor to the CoLab Program.[21,22] Situated cognition is retained as a design element in the CoLab Program, as the students are expected to learn about research, nature of science, and poster presentations in an authentic chemical research setting.[18,22,23] Situated cognition refers to the importance of how context influences learning.[20,21] Just as people learn words in the context of language transmission, both verbal and written, so too do budding science students learn the culture and practices of the wider community by being immersed (situated) in the culture of the community and learning its practices.[20,21,24] In the context of the CoLab Program, this involves learning about how to engage with the literature, document one's work in a laboratory notebook, to choose the proper equipment for a given laboratory task, handle equipment and materials safely, connect what occurs on a macroscopic level to what occurs on a microscopic level, to iterate and refine procedures, and prepare a presentation or publication.

The concept of authentic activities is central to the understanding of situated cognition. According to Brown *et al.*, authentic activities are, "…the ordinary practices of the culture."[20] Many of the practices that students engage in during traditional schooling are inauthentic because they do not reflect what professionals in the field actually do.[24] Traditional lab experiments often have students follow a procedure in a manual and obtain a result that is well documented and known to the instructor.[6,25] Thus, students are assessed according to if they can achieve the desired result. In contrast, scientists engage in research in which the outcome is unknown and, therefore, contribute new knowledge to the scientific community. The CoLab Program offers authentic research experiences for students. After an introduction to important procedures for the research environment, students begin to explore new, untested questions, often based in the literature, for procedures related to their given topic.[22] For example, in the CoLab sessions studied in this paper, students observed the inhibition of α-amylase by various food inhibitors through qualitative differences in color observed in well plates as well as quantitative measurement of absorption using *ImageJ* software and also modeled that inhibition in *PyMOL*.[18] They contribute to chemistry research in a way that allows new experiments to be developed for instruction that reflect contemporary research methods, such as fluorescence and, in the case of inhibition of α-amylase done here, direct demonstrations of inhibition by small molecules in food.

Meaningful Learning

Meaningful learning is used as the second theoretical framework for this study. As developed by Bretz and her coworkers, meaningful learning views learning as requiring integration of content knowledge (cognitive domain), performance of laboratory skills (psychomotor domain), and student feelings (affective domain).[19] The cognitive domain pertains to peoples' thoughts and reasoning abilities. In chemistry, examples of the cognitive domain include knowing how to find the order of a rate law or understanding how an inhibitor may affect enzyme activity. The psychomotor domain describes the ability to carry out tasks to support the learning of concepts. An example of the psychomotor domain in chemistry is carrying out a titration to determine the end point or how to use color to study the activity (and inhibition) of an enzyme. The affective domain describes peoples' feelings, goals, and motivations. An example of the affective domain in chemistry is understanding how learning impacts a hoped-for major in STEM or a career as a chemist or health-care professional. The affective domain is the least studied domain the literature thus far. Extensive work by Bretz brought the concept of meaningful learning into chemistry education with particular focus on the affective domain.[26,27] The affective domain in chemistry, for example, comes up when students talk about their career goals and the way they feel in the classroom or lab. By engaging in meaningful learning, students are better able to transfer concepts from one setting to another as students are able to connect concepts to each other.[28]

Meaningful learning has been previously investigated in traditional classroom settings.[19,27] By connecting this framework to that of situated cognition, this study aims to provide new knowledge about how the interplay of the cognitive, psychomotor, and affective domains occurs when students are placed in a CURE-based environment. It is crucial to evaluate if these more authentic research experiences deepen student understanding of the chemistry concepts, improve their laboratory skills, and increase student motivation to remain in STEM and pursue future careers in STEM.[22]

METHODOLOGICAL FRAMEWORK

Phenomenography

Phenomenography seeks to understand peoples' perceptions and experiences of a given phenomenon.[29,30] In this case, the phenomenon under study is the CoLab Program, in particular with respect to learning about research, how science is done, and poster presentations of research results. In his seminal paper on phenomenography, Marton states that there are a limited number of ways to conceptualize a given phenomenon.[29] Therefore, data collection and data analysis continue until no new categories to describe the phenomenon emerge. Phenomenography states that responses from participants are to be treated as truthful.[29] Consequently, there are no right or wrong responses in replies given from participants. The ultimate goal of a phenomenographic approach is to create an outcome space to describe peoples' experience with phenomenon of interest.[29,31] Outcomes spaces can be hierarchical or developmental.[31,32]

Several CER papers employed phenomenography as a framework. For example, Burrows *et al.* looked at how students perceived a project-based Organic Chemistry lab.[31] Following student interviews, 8 distinct ways that students perceived the lab were arranged in a developmental outcome space. These perceptions ranged from an apathetic perspective, where students did not care about the lab, to mastery, independent researcher, and explorer perspectives, where students valued gaining a richer understanding of organic chemistry concepts, enjoyed the experience of working alone to tackle new problems in the lab, and appreciated using their previously gained knowledge to solve new and unfamiliar reactions, respectively. In another study, Szteinberg and Weaver used phenomenography in a longitudinal assessment of CASPiE, which found that 48% of CASPiE students compared to 18% of traditional lab students remembered what they did in lab and why two and three years later with CASPiE students also stating their labs allowed for more creativity and deepened their understanding of authentic research while giving them the opportunity to engage in authentic research of their own.[33] Skagen *et al.* utilized phenomenography to describe collaborative learning in organic chemistry across the Internet using social media like Skype. They created an outcome space detailing the impact of the collaborative learning experience on students describing their attitudes, relationships, learning, and professional identity.[34] Finally, Reeves *et al.* used phenomenography in the context of virtual laboratory labs to present a continuum of how virtual laboratory labs hindered or enhanced student learning. This highlighted how virtual laboratory labs may be particularly useful for helping students understand concepts on a submicroscopic level.[35]

In phenomenographic work, it is important to document two perspectives that the investigators bring to the study. First, Stolz suggests that a phenomenological analysis of the essence of an experience should be conducted prior to a phenomenographic one.[36] This phenomenological analysis provides categories of description for the outcome space, which was done in this study. The data were then analyzed according to those categories. Therefore, some categories are present without representative quotes because they were not seen in the data amongst these six students.

A second important form of documentation is to state the positionality of the researchers explicitly. In this case, both authors were deeply involved with the CoLab and have an intimate familiarity with the set-up and running of the program—something that impacts the phenomenological description. The second author was in a position of leadership with respect to the program, including making decisions about the phenomena to be studied and developing many of the materials provided to the students. The first author interacted with the students, including sometimes in an instructional mode as well as in the process of obtaining consent for students to be part of the research program. At all stages of the research, it was made clear that participation in the research would not affect students' standing in CoLab, and the researcher did not try to influence student responses in any way during the interviews.

RESEARCH QUESTIONS

This research investigated the following question: How do students in the UIC STEM Initiative CoLab Program experience the program? The question uses the frameworks of situated cognition and meaningful learning in seeking to understand how a workshop-based research experience in chemistry may facilitate (or hinder) student learning about research, how science is done, and presentations. Since the program more closely resembles authentic research carried out by scientists, it is hypothesized that students will display meaningful learning in all the domains. Students will gain experience in conducting their own research with failure and iteration baked into the process instead of following a procedure, and they will demonstrate their learning of concepts and lab skills through the poster presentation, which may present a positive affective experience to motivate and interest students into pursuing science careers in the future. Addressing this question is an initial step in a research program that will, we hope, contribute to better understanding of how initial experiences with research impact the retention and graduation of diverse students in STEM.

METHODS

Setting and Data Collection

The study described in this article included both students in a CoLab Program following *in vitro* procedures built on prior work published by Maqsood *et al.*[37] and Yilmazer-Musa *et al.*[38] as well as in silico procedures built on prior work published by Acuna *et al.*[39] and described earlier.[18] In this case, informed consent was obtained from six students, two from the six week summer 2021 CoLab and four from the January 2022 mini-CoLab. The summer students were all first-year entering students while the mini-CoLab students had all completed at least one semester of work at the university. Two of those were transfer students who had two or more years of prior higher education experience. They all received a one-hour orientation to the program the week before it started. They also were given standard procedures and a research paper to use for their ideas about research. During the summer workshop, students met once a week for six weeks for approximately three hours per day. Mini-CoLab students met for six hours per day for three consecutive days. All meetings and work were done remotely, using a kit that had been sent to them. During the final session of the CoLab, students presented their work in a Zoom poster session to other students and faculty members not involved in the CoLab.[17,40,41] A poster template, which included introduction, methods, results and conclusions sections, was provided to students prior to their presentation, which they used to format their data. Previous research has also used posters as assessment tools for students in chemistry[17,42], including for upper division courses[40] and virtually.[40]

All research on student experiences was conducted with a protocol approved by the University's Institutional Review Board (STUDY2021–0457). Students in this study participated in one semi-structured interview via Zoom[43] after completion of the CoLab Program. Interviews ranged from 18 to 31 minutes. Demographic information about the students is provided in the Supporting Information. A semi-structured format was used to allow for follow-up to any interesting points raised by students that had not been conceived of prior in the interview questions.[44] An 18 word affective word matrix taken from Galloway *et al*. was used during the interviews to allow students to indicate their feelings towards the CoLab.[19] This article focuses on student responses to this interview. Students also granted access to any artifacts that were created during the CoLab, such as the posters that they presented.

Data Analysis

Data was analyzed using the phenomenographic research process outlined by Bowden and Green.[32] The overall research process followed the steps shown in Figure 1. All interviews were completed before data analysis began and were initially transcribed using Microsoft Word 365. Transcribed interviews were cleaned up by the first author for readability. Qualitative coding occurred using MAXQDA 2020.[45] Transcripts were read and reread to construct categories about the phenomenon of interest, and these categories were refined in discussions by both authors with further rereading.

Open coding was used to determine major categories of thought that occurred in the student interviews. Coding was done through the process of thematic analysis based on the theoretical frameworks. Thematic analysis can be used with a variety of theoretical frameworks.[46] Codes were created for pieces of data that appeared interesting, and that pertained to how students experienced the CoLab Program, for example, their comments on the feedback they received during the poster presentation. Particular focus was on aspects where students compared and contrasted the CoLab format with past labs and on the presence of the cognitive, psychomotor, and affective domains in their responses. Coding proceeded through stages until saturation was achieved, e.g., no new open codes were created. Upon completion of open coding similar codes were grouped into themes.[46] These themes pertained to how research connects to students' lives and future ambitions, nature of science, working with others, and creating a final representation of their lab work for others to view, which were major aspects of the program discussed by students in their interviews. Similar themes were then further grouped into cross-cutting themes that collapse the aforementioned themes into three cross-cutting themes pertaining to how students viewed the research process, the process of doing science, and the poster creation and presentation process.

Table 1 summarizes the outcome of the coding process. We first list the open code from the data analysis along with a brief description and the frequency of the code across all six interviews. Then, we group the codes into themes and relate those themes to the three cross-cutting themes we use in the study: related to student understanding of research, the nature of science, and poster presentation. Some codes fall under multiple themes. For example, "future research" relates to both how students understand research and their understanding of the nature of science.

Additional insight into the student experience was also obtained by the use of a matrix of 18 feelings taken from Galloway *et al.*[19] A large majority of feelings (68%) described by the students towards the CoLab were associated with positive affect by Galloway *et al.* (see Figure 2).

RESULTS

Our research results are presented as a means to answer the question "How do students in the UIC STEM Initiative CoLab Program experience the program?" To do this, we present the outcome of the data analysis given in Table 2 and Figure 3 in the form of a phenomenographic outcome space that details how meaningful learning intersects with how students viewed their understanding of the research process, how students viewed the process of doing science, and how student viewed the poster creation and presentation process in the context of a workshop-based undergraduate research experience. Outcome spaces can be arranged hierarchically or developmentally.[31,47] The current study arranges the outcome space developmentally following a previous outcome space published by Burrows *et al.* as an example.[31] Meaningful learning being enhanced due to CoLab is the ideal desired outcome. Categories are arranged from left to right from less complex to more complex with factors that are a part of a given category across cross-cutting themes listed below said category (see Figure 3).

Central to phenomenography is creating descriptive categories from the data gathered.[48] These are the categories used to describe the collective conceptions of the cross-cutting themes in Table 1. These categories within the present study are:

1. Meaningful Learning was Impeded Due to CoLab
2. Meaningful Learning was Neither Impeded nor Enhanced Due to CoLab
3. Meaningful Learning was Enhanced Due to CoLab

Descriptions and representative quotes of each cross-cutting theme linked to each category of description are depicted in Table 2. The cross-cutting themes in the outcome space are described in more detail below.

As shown in Table 2, our outcome space has three cross cutting themes and, for each, three categories of student experiences. This creates a 3 × 3 matrix, within which we are able to cover the breadth of how students expressed their experiences. As noted, the outcome space describes the logical relationship of the cross-cutting themes and experience categories. But there are some portions of the outcome space where we do not have an example of a student experience within this data.

How Students Viewed Their Understanding of the Research Process

This cross-cutting theme describes how the research the students conducted in the CoLab connects to their personal lives, their future class or job interests, or both. A key component of meaningful learning in the affective domain is motivation. This is exemplified in an excerpt from student SP02 2022 who saw how the research the students conducted could help people with diabetes. Since they know many people with diabetes, they felt more motivated to pursue the research and more clearly saw the immediate value in the research:

> "I have people, I know people and have people in my family who are diabetic so I can see how this can directly, you know. So, I can like use this. I can like talk about this, it's just I think my background all in all, in general, just was really, really good. This experiment was just very, I was motivated in that sense."

Another example is given by student SP01 2022, who commented on how the CoLab caused them to expand their original STEM ambitions. They originally had not planned to pursue a PhD, but after participating in the CoLab, they expressed a stronger desire to go to graduate school and obtain such an advanced degree:

> "I do think that it kind of helped me understand what like was going through the scientists' minds and it kind of like influenced me like now. I'm kind of thinking about, oh like should I get my PhD should I like, you know, maybe it makes me want to like go into research a little bit more for sure."

The actual research process was also a source of motivation. Student SP01 2022 additionally demonstrated meaningful learning in the cognitive domain when relating data back to the initial hypothesis and explaining the importance of the research. Another example of learning in the cognitive domain is present when student SP04 2022 discussed the systematic nature of the research process as well as using the literature to gain an initial understanding of a given research topic and discussed practical outputs like creating new medications.

The relationship of the students' affective experience to their experience of research carried over to cases of research failures. Student SP03 2022 highlighted a setback in their own research:

> "I thought 'cause I have like this like water purifier. It lets like you can put out cold water. You can put out hot water. And I was just using the hot water from there, but

> I didn't like process in my brain that boiling means you should see some bubbles in the water. There weren't any bubbles in the water, so my water wasn't hot enough to like get it going."

This is an important finding as failure is a key part of the research process. Failure allows research experiences to be more authentic.[49] This contrasts with labs where students simply replicate results. The CoLab environment was much more authentic and closer to the ill-defined procedures actual scientists draft and improve on. Failure also allows for iteration to occur. The above example also shows the intersection of the three domains with the student realizing the error in their understanding of boiling (cognitive), carrying out the necessary steps to fix the error (psychomotor), and persevering through this challenge (affective). This may point to an important way in which research is particularly valuable for meaningful learning across all three domains.

The degree to which students had previous research experience influenced whether or not the CoLab provided them with a deeper understanding of the research process. Students FA01 2021 and FA02 2021 were new to research and both mentioned becoming familiar with the breadth of questions that can be addressed through research, as in this quotation from student FA02 2021:

> "Like looking at what type of like enzymes could affect our end product, so I feel like research has like a bunch of avenues for you to delve like more into a specific topic and like one specific branch of your entire research….Just like there's a lot of depth you can go into or you can just like do research about a general topic."

There are cases where prior experiences meant the CoLab experience did not actually add to student understanding of research. Students SP01 2022, SP02 2022, SP03 2022, and SP04 2022 all stated that the CoLab did not deepen their understanding of the research process.[27]

How students viewed the process of doing science

This cross-cutting theme describes how students understood the process of doing science as well as the people involved in science. This theme encompasses insights into the nature of science as well as chemistry content knowledge and lab skills. All students broadly described science as the study of natural processes as well as the natural world. Some students went deeper into specific fields. For instance, student FA02 2021 stated:

> "I would define science as the way things work, such as like the human body or like more like physics or technology like how they work and chemistry like how reactions occur and like the relationship between objects, I guess, and like talking about chemistry, the relationship between like atoms or biology the relationship between different systems."

All students gave thorough responses regarding "who does science" and all came to see that anyone can do science. They attributed this to the CoLab experience. This highlights the value of authentic research in deepening students' nature of science conceptions. Prior to the CoLab, the students believed that only people with advanced degrees or graduate students could partake in more advanced scientific inquiry. This is highlighted in the following representative quote:

> SP01 2022: "…I understand that like it's not just like you know, people who have like who have like their PhD's after years to like do this important research, but it can be like anyone who's like you know, like me, like a freshman in undergrad or even like a high school [student] or even up till, you know, people who have their people who have multiple PhD's and advanced degrees. Now I kind of understand that like now like any, anyone can theoretically do research long as they have a controlled environment, and they know what they're doing."

Students came to see that such an environment does not necessarily have to be an on-site lab. Due to the COVID-19 pandemic, these students participated in the CoLab from the safety of their homes. Students FA02 2022 and SP03 2022 mentioned that science can be done in any environment and that it does not necessarily have to be a research or teaching lab.

With respect to nature of science and the cognitive and psychomotor domains, some students voiced that they gained a deeper understanding of what they were doing and what the macroscopic observations they viewed meant in terms of the chemical reactions occurring. This was contrasted to the experience of simply following the instructions provided to them. Developing competence in understanding of concepts and lab skills also translated into satisfaction in the affective domain as previously discussed. This is encapsulated in a quote from student SP01 2022:

> "…but I feel like with this lab I was very like I was excited to like finally know, okay, like this is what's going on at the atomic level. This is what? This thing is doing like the iodine is showing the blue. Oh, they start the amylase is breaking down the starch like I had a very like nice understanding which like made me really happy and everything."

Not every student voiced such a deeper understanding of the actual science behind the CoLab. For example, student FA01 2021 stated that they did not learn the actual structure of how α-amylase and their group's chosen food inhibitor interacted. This student understood that the food inhibitor studied influences the amylase, but they could not verbalize specifically that it reduced the effect of the α-amylase on the starch-iodine complex and caused less decay of its characteristic blue color compared to an uninhibited sample.[18]

Students also discussed the role of collaboration in doing science. The majority of students found that working in small groups helped them to better understand the science as well as increased their confidence. Collaboration alone may not be sufficient as student interest is also necessary to persevere. This is manifested in a quote from student SP02 2022:

> "Like I was, I know I at the beginning I was a little intimidated by the programs that we were getting used to when I would test them out at home. I'm like, oh, I don't think I understood. And this, but I feel like the interest that I had, and that all of our group members had when we worked together, was enough to kind of power through and understand it."

This student demonstrated that when they did not understand how to use programs, such as PyMOL, during CoLab, working together with group members who all had an interest in the work allowed them to develop a better understanding of the program and increased their confidence. Working in groups was not equally helpful to everyone, however. In contrast, student FA01 2021 discussed having little communication in their group. This hindered understanding of the chemistry and fostered a more negative group mood:

> "Uh, not really just because it was so few of us [in a group], and out of us, I believe there was very…not a lot of communication. There was a lot of independent work…. Yeah, I'd say also the fact my group was so small for the whole process made the whole thing more nervous."

How students viewed the poster creation and presentation process

This cross-cutting theme describes the poster presentation in the final week of CoLab. Students expressed their thoughts about the impact the poster creation and presentation process had on their understanding of their research topic as well as their ability to clearly articulate said topic and present it visually. Students FA02 2021, SP01 2022, SP03 2022, and SP04 2022 found the poster presentation deepened their understanding of their topic, thus learning in the cognitive domain. Student SP03 2022 maintained:

> "I've learned a lot from it 'cause before I had no clue what amylase was or like. Yeah, I just had no clue about everything that happened before, but like organizing them onto 1 slide and like going back through all like my data, it all just started making a lot of sense."

All six students reported becoming more proficient at presenting their data visually and becoming more adept at orally explaining their data to others, key advancements in the psychomotor domain.[15,40] The creation of a cohesive representation for others to view was a big motivation for student FA01 2021 despite not learning all the chemistry behind how α-amylase interacts with their chosen food inhibitor. The poster presentation improved their confidence and proved to be a more positive affective experience compared to the rest of CoLab for this student. This is evident in the following quote from the student:

> "I'd say I have improved. Just now I can feel more confident about presenting what I know. Just that more experience makes for better presenting…. So, I'd say it was like a pretty respectful environment. So I'd go over everything I had as they came in. For the most part, it was letting me go through the whole presentation before asking questions. And some did engage in a lot of questions while others just stayed for the presentation. But I did like, when they actually took time to just talk to me and go over how a presentation should be and ask me questions that I don't really know the answers to. It was just fun to try to figure it out."

All students also found the scaffolding provided through a poster template to be helpful. Students additionally discussed having examples of posters that a lot of people went to see versus ones that didn't garner as much attention as being supportive. Student SP02 2022 provides a representative quote of how this template came in handy:

> "Uhm, I really liked when Dr. [Redacted] showed us examples of a poster that was you know that attracted more people and that people were able to kind of read through and actually like gauge your attention to versus a poster that might intimidate people and have them not complete….'cause I remember I used to when

> I did, when we did my poster I was like looking back I was like 'Wow. Did we have so much writing in ours like I was thinking of that and I was like. OK, let's make sure not to do that'…. So, I definitely got more of a sense of what would attract people to your poster."

Students FA01 2021 and SP02 2022 additionally maintained that the feedback they received was helpful in making them think about their data and future research to conduct. Student FA01 2021 mentioned that someone who viewed their poster was colorblind, which caused them to think about how to display data to be more accessible to all kinds of people in the future.[50] Student SP02 2022 received a question inquiring how the results of their experiment may have changed if pancreatic amylase was used instead of salivary amylase. This demonstrates that students benefited from feedback within the communication process, which is something that occurs at actual scientific conferences. Future iterations of this research will more explicitly probe at the influence of audience feedback during the poster presentation.

A factor that diminished the benefit of poster preparation and presentation was time. Due to the three-day format of the January 2022 CoLab, everything took place on a very condensed scale compared to the six-week format used in Summer 2021. Student SP04 2022 mentioned that time constraints prevented this student from learning as much about their research topic when synthesizing the data as they could have with a longer time period between data analysis and poster presentation. And student SP03 2022 admitted to not thoroughly preparing for the poster session, which had an impact on their understanding of their research topic.

Group communication also hindered the learning with the poster presentation. As previously mentioned, student FA01 2021 reported not learning the topic due to poor communication within their small group. Since the poster presentation was a group effort, this makes sense that poor communication would result in less learning. In the future, we will try to better scaffold student learning by having them complete weekly progress reports on what they got out of CoLab that week to improve communication and provide a record for students to synthesize their thoughts as the poster presentation approaches.

DISCUSSION

The previous section, including the results summarized in the outcome space of Table 2, provides important insight into broader questions about the benefit of this program for students, and perhaps for the benefit of CURES in general. We discuss these with respect to the two major theoretical frameworks for this study: meaningful learning and situated cognition.

In the area of meaningful learning, the results contain several examples where the student experience includes clear linkages among the three domains: cognitive, psychomotor, and affective. In the area of understanding research, students came away with positive reports of learning in the affective domain, something indicated when students described feeling more motivated to pursue research in the future and some even expanded their original ambitions as a result of participating in the CoLab. This grew from the experience of doing the work and also learning about connections of research to authentic problems. This underscores the value of connecting research to students' personal lives and/or future job interests.

Learning associated with nature of science also occurred through a combination of the three domains. Student SP04 2022 mentioned feeling comfortable in the CoLab environment. This is significant because as a Hispanic female, student SP04 2022 may feel pressured to live up to expectations or face imposter syndrome.[51,52] The CoLab and other similar programs offer value in providing students with a place where experience that they belong, and they too can engage in science.[53–55]

All students reported being challenged by the CoLab and highlighted this as a positive feeling, which they contrasted with being bored, which is how they often felt in traditional labs in high school. This even occurred when failure was present, since this reinforces previous results of students pairing certain words in the affective words matrix together.[19]

In the area of situated cognition, the majority of students in the UIC STEM Initiative CoLab Program detailed the processes of data collection and data analysis and also mentioned failure as an important part of the research process. Not all research works out, and the context of the CoLab Program allowed students to see this firsthand. Our results include evidence that learning how (psychomotor) and what to do (cognitive) grew out of an experience of failure, but that this clearly left the student with a positive affective experience. Getting a negative result is also part of doing research even if such results are not usually published in scientific journals.[49] Thus, more meaningful learning, even with a negative event, may depend on the authentic situation. On the other hand, we note that no student mentioned the role of iteration in research. This is concerning as research often involves modifying procedures to more effectively answer a research question or if the first round of results is inconclusive.[22,49] That said, this may have occurred due to the interview protocol not explicitly questioning students about this aspect of the research process. Future revisions of this research will ask students about the importance of iteration in research.

Students also came to see the different avenues of authentic research available to them. Several students were not aware of the fact that science can also be conducted *in silico* by relying on such programs as *PyMOL* and HDOCK/Patch Dock.

Several students expressed a deeper understanding of thinking about what is occurring in the chemistry at a submicroscopic level compared to traditional labs. Thanks to the CoLab environment, students additionally began to understand that science not only involves work in the wet lab but can also include an online environment, such as *PyMOL*.[56] This underscores the importance of introducing students to technology utilized by science professionals during their undergraduate studies. Not all STEM students may want to go into wet lab work and being familiar with various programs that scientists use may influence students to work *in silico* in STEM in the future instead of exiting STEM entirely if they do not enjoy lab work.

Finally, the integrative work required for the presentation of results, which reflects situating assessment in an authentic practice, was a place for meaningful learning to emerge. Even when students did not learn some content deeply, they perceived value in presenting and organizing their data. The majority of students discussed how creating a poster compelled them to look more into the details of what they did instead of generalizing their research. Presenting the poster also elicited feedback that helped them to consider aspects of their research they had previously not thought of, such as representing their work to colorblind users and what impact using pancreatic instead of salivary amylase would have on their data, respectively. This is in agreement with previous research on the subject of student poster presentations.[15] Of the students who did not improve their understanding of their research topic during poster creation and presentation, the factors cited were lack of time in preparing for the presentation as well as a lack of communication during small group work. Future versions of the interview protocol will be modified to improve on the feedback aspect of the presentation.

CONCLUSIONS

This study resulted in an outcome space with three categories describing whether meaningful learning was impeded, neither impeded nor enhanced, or enhanced due to CoLab. It offers insight into how the elements of this workshop facilitate meaningful learning in multiple ways. Allowing students to explore a topic with a degree of independence and with good scaffolding fosters more positive affect and allows students to overcome challenges that they typically wouldn't encounter when simply following steps in a laboratory manual. The results showcase how such outcomes are situated within the specific context of this workshop experience.[22] Student understanding of the research process was more mixed. Students fared better with respect to who does science and how science is done with students coming to realize after participating in the CoLab Program that anyone can partake in science as long as they have a controlled environment. With respect to nature of science, they came to realize the different modalities of research that are available. Students also deepened their learning of concepts introduced in CoLab, honed their visual presentation and oral communication skills, and increased their motivation by working towards the final goal of a poster presentation.

The results also point to possible areas for improvement in the CoLab Program. Although students engaged in repetition during the CoLab and some even mentioned repetition during their interviews, they did not discuss the importance of iteration or repeatability in research. There is more need to emphasize to students what science is and what distinguishes it from non-science fields as no student in this study made such a distinction, and the broad definitions of science provided by students do not clearly demonstrate their understanding of this aspect of nature of science.[57]

Limitations

This study investigated a workshop-based undergraduate research experience at a single university. Therefore, the data may not reflect other institutions. Additionally, the number of participants (n=6) in this study was small. Incoming freshman may have felt more anxious about the transition from high school to university during this trying time, so fewer signed up for the study. It is difficult to say that the outcome space created in this study is saturated due to the small number of participants and, indeed, part of the space has no examples from this group of students. Some limitations may also arise because of the chemistry-focused nature of the presentation. The lack of a graduate student or faculty member in computer science or engineering may have impacted the learning and understanding of students in the *in silico* track.[20]

Future Directions

This study is part of a larger study on student belonging and self-identity in science with such constructs as student affective experience and understanding of nature of science constituting students' self-identity. Sense of belonging[58–60] and science identity[61–67] are well documented in the literature but not in this setting of a workshop-based undergraduate research experience. The categories described in this article will be used to flesh out a conception of the identity of incoming freshmen. Future research on the CoLab will also include survey data[57] in addition to interview data as an additional means of validation of the data and will include a one-year follow-up with students to probe their learning and understanding one year after conclusion of the CoLab.

This study has also provided insights that will be useful in the practical setting of program design. This includes more explicit discussion of the importance of iteration and reproducibility in science, differences between the nature of science and the nature of other disciplines, and better scaffolding for *in silico* work by experts in that software. In the future, it may be wise to space out the three days in the mini CoLab by having them on alternate days of the week instead of back-to-back-to-back.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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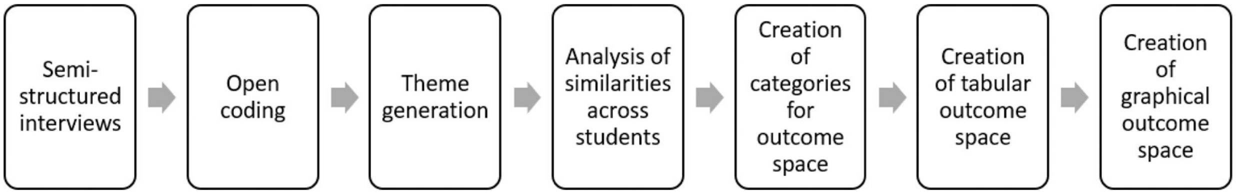

Figure 1. Steps Involved in the Research Process.

Six students participated in semi-structured interviews from which codes and themes were derived. These themes were used to create tabular (see Table 1) and graphical outcome spaces (see Figure 3).

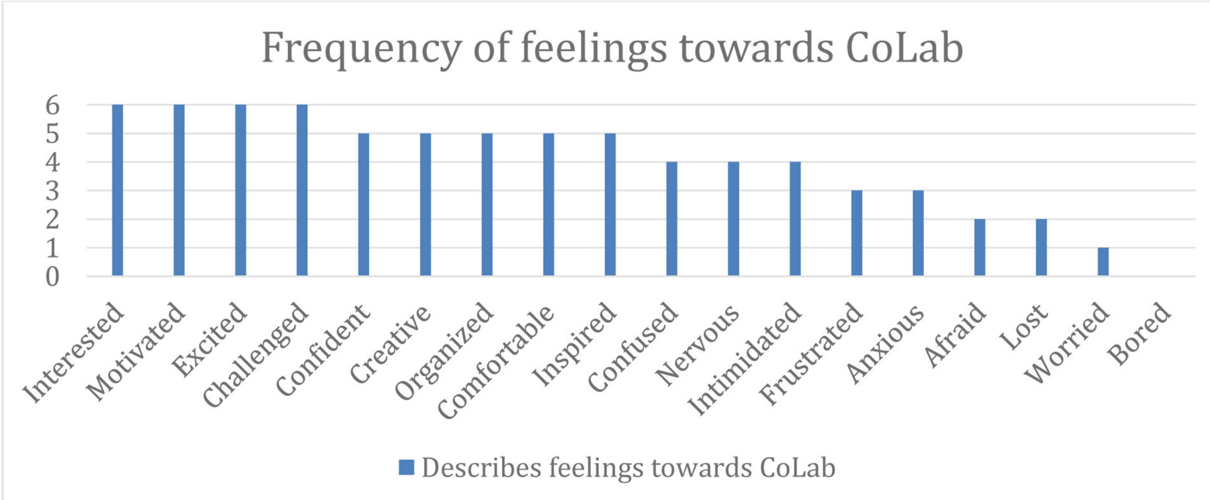

Figure 2. Bar Graph Displaying Frequency of Words Students Used During Interviews to Describe their Feelings Towards CoLab.

Word Matrix taken from Galloway et al. 2016[19]

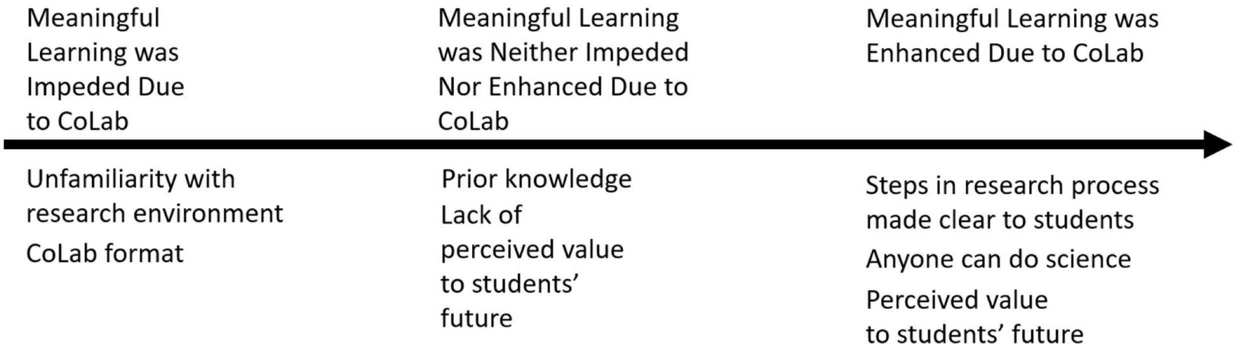

Figure 3.
Graphical Representation of the Outcome Space

Table 1.

Codes, Description of Codes, Frequency of Codes, and Themes from Student Interviews and related to Cross-cutting themes for the research

<table>
<tr><th>Code</th><th>Description</th><th>Frequency</th><th>Theme</th><th>Cross-Cutting Theme</th></tr>
<tr><td>Previous research experience</td><td>Previous research experience of the student.</td><td>9</td><td rowspan="3">Research Experience and Future Interests</td><td rowspan="6">How students viewed their understanding of the research process</td></tr>
<tr><td>Future research</td><td>Future research plans/interests of the student.</td><td>18</td></tr>
<tr><td>Basic vs. applied science</td><td>Student compares and contrasts basic vs. applied science.</td><td>2</td></tr>
<tr><td>Connection to personal life</td><td>Student connects CoLab to personal life.</td><td>2</td><td rowspan="3">Connecting Research to Personal Life</td></tr>
<tr><td>Connection to future job interests</td><td>Student connects CoLab to what they'd like to do in the future.</td><td>1</td></tr>
<tr><td>Technology</td><td>Student describes experiences with using technology and how that knowledge may be helpful for them in the future.</td><td>5</td></tr>
<tr><td>Requirements to be a scientist</td><td>Students discusses requirements for one to be or become a scientist.</td><td>2</td><td rowspan="3">Doing science and science experience</td><td rowspan="12">How students viewed the process of doing science</td></tr>
<tr><td>Science professionalism</td><td>Student distinguishes between science professionals and science students.</td><td>7</td></tr>
<tr><td>Controlled setting</td><td>Student references controlled setting in which research is done.</td><td>3</td></tr>
<tr><td>Future research</td><td>Future research plans/interests of the student.</td><td>18</td><td rowspan="4">Future goals, opportunities, and support networks</td></tr>
<tr><td>Apply what we learned to new environments</td><td>New skills in other areas can be learned quicker based on what was learned in CoLab.</td><td>1</td></tr>
<tr><td>Retention in STEM</td><td>Student expresses desire to remain in STEM.</td><td>2</td></tr>
<tr><td>Future job interests</td><td>Student connects work in CoLab to what they'd like to do as a career in the future.</td><td>1</td></tr>
<tr><td>Small group</td><td>Student describes working in small groups.</td><td>7</td><td rowspan="2">Social aspects of doing science</td></tr>
<tr><td>Social collaboration</td><td>Student describes working together with others.</td><td>4</td></tr>
<tr><td>Connection to personal life</td><td>Student connects CoLab to personal life.</td><td>2</td><td rowspan="3">Connecting research to personal life</td></tr>
<tr><td>Connection to future job interests</td><td>Student connects CoLab to what they'd like to do in the future.</td><td>1</td></tr>
<tr><td>Technology</td><td>Student describes experiences with using technology and how that knowledge may be helpful for them in the future.</td><td>5</td></tr>
<tr><td>Presenting data</td><td>Student discusses creation of poster and how to display data.</td><td>5</td><td rowspan="2">Creation of cohesive representation for others to view</td><td rowspan="2">How students viewed the poster creation and presentation process</td></tr>
<tr><td>Poster differences</td><td>Student discusses differences between poster made in CoLab and previous posters made in high school.</td><td>3</td></tr>
</table>

Code	Description	Frequency	Theme	Cross-Cutting Theme
Unexpected poster finding	Student discusses an aspect of poster presentation they had not previously considered.	1		
Poster organization	Student discusses how example of poster helped them create their own.	1		
Deeper understanding	Student discusses how poster creation helped them to develop a deeper understanding of their research topic.	4		

Table 2.

Tabular Representation of the Outcome Space Cross-cutting themes are presented along with definitions for each category of description alongside representative quotes for each theme.

Cross-cutting theme	Category 1: Meaningful Learning was Impeded Due to CoLab		Category 2: Meaningful Learning was Neither Impeded nor Enhanced Due to CoLab		Category 3: Meaningful Learning was Enhanced Due to CoLab	
	Definition	**Quote**	**Definition**	**Quote**	**Definition**	**Quote**
How students viewed their understanding of the research process	The workshop-based undergraduate research experience overwhelmed students with solving a scientific problem on their own so they did not reflect on the research process.	N/A	Students already developed an understanding of the research process prior to participating in CoLab, and the CoLab experience did not change their understanding.	SP01 2022: "Oh, I think I have a pretty good understanding of research as I'm in like a couple of different programs that help me like find research and kind of push for me to do a lot of research, so they give us a lot of information on that. So, I think I have a pretty good amount of like knowledge on that."	The CoLab environment deepened student understanding of the research process and brought to their attention steps involved in research they had not previously considered and/or alternate methods to pursue research.	FA02 2021: "Um, definitely like the hard work that goes into research and like the amount of support it gets, I feel like there was a lot of emphasis on like what avenues you can take and like what resources you have like yourself to fund your research or like how to start research just like that first step, like for CoLab we went like two kinds of different routes like the more computer-based, mathematical approach like using the PyMOL program and then what I did, like the more biological side of things. Like looking at what type of like enzymes could affect our end product, so I feel like research has like a bunch of avenues for you to delve like more into a specific topic and like one specific branch of your entire research."
How students viewed the process of doing science	The format of the CoLab with students working to understand their own research hindered student learning.	FA01 2021: "I believe there was very…not a lot of communication. There was a lot of independent work…. I learned that while they're [amylase and food inhibitor] together, I never learned the proper structure. So not much changed on gaining the specific knowledge on my topic."	Students entered CoLab with prior experience about the process of doing science, and the CoLab did not change their perceptions.	N/A	Students came to realize that they can partake in more complex experiments akin to what researchers do.	FA02 2021: "Uh, I think I like before like, obviously like in high school like we do chemistry experiments, but I feel like they weren't as like….They were hands-on but they weren't as like complicated, they were more based towards students, but I feel like the STEM CoLab, especially because it was all online and we were like doing it from our houses, I felt like much more like take it seriously, I guess. I was doing the experiment and like, it felt like, a substantial experiment, like it didn't feel like a kid experiment basically. So like based on who conducts research, before I would have said like only scientists or like only researchers."
Cross-cutting theme	**Category 1: Meaningful Learning was Impeded Due to CoLab**		**Category 2: Meaningful Learning was Neither Impeded nor Enhanced Due to CoLab**		**Category 3: Meaningful Learning was Enhanced Due to CoLab**	
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How students viewed the poster creation and presentation process	Students perceived the poster creation process and presentation process as interfering with	N/A	CoLab did not provide students with additional value of how the poster creation process or	SP02 2022: "Um, I don't know about change. I feel like I mentioned the program that I was in it was it was through the Hispanic Center of	Students perceived value in the process of poster creation in terms of application in the future and/or	FA02 2021: "Um, I feel like making the poster kind of forced us to look at more details and not just give like a generalized 'Oh, this is what we learned.' We learned that like the strawberries inhibit

	their ability to understand their research topic.		learning of their topic through creating a poster would be useful in the future.	Excellence. And there's was, like, uh, I'm gonna say eight-week program and we had one class completely directed to the literature review. And, you know, being in high school, they are going to assume that we haven't never done one, so they went in so much depth and we started our literature in like week two, so we spent like, um, we spent seven weeks like 6–7 weeks doing this literature review so um and creating this poster. So, we did those like we basically did those big giant ones with every single aspect of it so I wouldn't say my view on doing that changed."	understanding of their research topic.	the amylase. So I felt like just kind of presenting it in a poster made us look more deeper into our topic. Uh, I would say like before my high school did make us make posters and stuff, but we never like presented them, but I feel like having the opportunity to like present my work was really beneficial just because I feel I know how to better explain the topics that I'm researching."