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Developing Meaningful Learning in a Freshman-Level Chemistry Course for Non-STEM Majors

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Abstract

Undergraduate students take general education course work in a variety of topics including natural science. These general education courses offer opportunities to improve teaching and introduce more authentic learning experiences. In the 21st century, courses, including science laboratories, can be offered via different modes: online, remote, hybrid, and face-to-face [F2F]. Here, we share the original development and implementation of an authentic, problem-based learning [PBL] experience in a chemistry course for non-majors as well as how that same PBL became a way to maintain students' authentic experiences during the move from F2F to remote due to the COVID-19 situation.

Keywords: PBL, problem-based learning, chemistry education, authentic problems

Developing meaningful learning in a freshman-level chemistry course for non-STEM majors

Alles leben ist Problemlösen. [All life is problem solving]

Karl Popper (1994)

General education course work is standard in colleges and universities in the United States and is often a key component of the first two years of study (Walker, 1961). This general education course work most often includes courses in science, mathematics, history, language / communication (e.g. English composition, speech), and social science (e.g. introduction to psychology). As questions regarding the benefits of a liberal arts education emerged within the last decade or so, assessment began to find a strong footing. The assessment movement, in turn, led to the requirement of learning outcomes especially within the general education curriculum. Common learning outcomes often include communication (writing) and critical thinking (Miller & Sundre, 2008). In fact, Association of American Colleges and Universities (2007) states that teamwork, communication, problem solving, and social responsibility are both the skills employers seek and are among the learning outcomes of most general education programs. However, Miller and Sundre (2008) found that college students often do not value the general education course work they must take for their undergraduate degrees. This general disinterest and disconnect with general education course work leads to a lack of student motivation to learn within these courses primarily because students believe that these courses are unimportant for their chosen majors. Walker (1961) discussed the longevity of the types of course work included in general education including courses in natural science, such as chemistry.

Within this manuscript, we describe the major revision of a laboratory-based general education chemistry course for non-STEM (science, technology, engineering, and mathematics) majors. Chemistry for Everyone (CFE) is a conceptual chemistry course offered at a large, public university in the Midwest. Although the lecture portion of the course remained unchanged, the laboratory was re-envisioned. Thus, the laboratory moved from a typical freshman-level chemistry lab for non-STEM majors to one that included a major semester long problem-based learning (PBL) activity. This PBL activity was designed to engage students in an authentic chemistry experience. Students also performed some of the traditional CFE laboratory experiments (see Appendix B for the schedule and number of laboratories run).

However, the CFE course was forced to adapt to the changes created to instruction in higher education due to the COVID-19 pandemic. Like most university courses, the pandemic forced face-to-face (F2F) courses such as CFE to move online. These changes, of course, affected the plans for the PBL experience as well as the regular chemistry experiments retained.

As a result, the traditional CFE laboratory experiments became situations where students observed videos of graduate students running the laboratory activities. CFE students were then provided data. However, the PBL activity progressed with little modification, and students were able to perform hands-on laboratory activities. Overall, there are few examples of using a PBL approach within college chemistry courses and even fewer where PBL is used to teach the laboratory sections of a large-size undergraduate, general education, chemistry course. Additionally, this type of laboratory experience offers an opportunity for online chemistry courses especially those that serve as general education courses such as CFE.

Chemistry for Everyone

CFE is a four-credit-hour, laboratory-based chemistry course. The official course description states that CFE offers,"Integrated, hands-on, laboratory instruction in the fundamental concepts of chemistry for general education and middle-level licensure for pre-service and in-service teachers." The lecture meets twice a week, 1.5 hours each for 3-hours total per week; the laboratory meets twice a week, 1.5 hours each for 3-hours total per week. In its original form, CFE did not include a laboratory experience. Graduate teaching assistants teach the laboratories, and a full-time chemistry faculty member teaches the lecture. Within this manuscript, the terms instructor and laboratory instructor refer to the graduate teaching assistants who are also co-authors of this paper.

CFE is part of the natural science general education course work offered at its associated university. Thus, CFE must meet the university's natural science general education course learning outcomes. These outcomes are as follows for chemistry:

- Demonstrate knowledge of major concepts, findings, and historical perspectives in chemistry
- Find information resources in chemistry and evaluate their reliability.
- Articulate the role of ethics in chemistry.
- Demonstrate an understanding of scientific and technical issues at a functional level and articulate how they impact our society and economy.
- Articulate the nature of the scientific method, apply it through hands-on laboratory experiments, and critically evaluate applications of the scientific method.
- Solve quantitative and qualitative problems in the natural sciences
- Demonstrate effective written and oral communication appropriate to chemistry.

Issues in chemical education

Various researchers over the last decade (e.g. DeVos, et al., 2003; Hofstein & Lunetta, 2004; Udo, et al., 2004) have cited issues with students' learning experiences in college-level chemistry for non-majors. For instance, DeVos, et al. (2003) discuss various issues within chemical education including the lack of authentic and meaningful roles for students in their chemistry coursework. The lack of authentic, meaningful roles for students is especially problematic within general education chemistry courses. Udo, et al. (2004) found that science anxiety is also an issue in general education science courses for non-science majors, especially for female students. Negative experiences in prior science courses, including laboratories, are often connected to students' science anxiety (Udo et al., 2004). It is no doubt helpful to see how chemistry education has changed over the last 50 years to understand the evolution of chemistry teaching.

Starting in the 1960's, in the post Sputnik era, chemical education began to change significantly. Instruction moved away from reasoning and discussions. This was done to refocus chemical education toward general chemical theories such as atomic structure and bonding (DeVos, et al., 2003; Hofstein & Lunetta, 2004). Thus, ideas that had encapsulated the development of chemical knowledge such as evidence, reasoning, and competition of ideas were removed from the curriculum due to lack of time (DeVos, et al., 2003). However, Hofstein and Lunetta (2004) performed a literature review over a 22-year period. They found, since 1982, an increasing number of laboratory teaching approaches and strategies such as PBL, discovery, and inquiry. As such, Hofstein and Lunetta (2004) summarized that these changes are a result of contemporary goals for science learning, current models of how students construct knowledge, and information about how teachers and students engage in science laboratory activities.

Similarly, Tobin (1990) suggested that, if the students are given opportunities to manipulate equipment and materials in an environment suitable for them to construct their knowledge of phenomena and related scientific concepts, learning that is more meaningful is possible in the laboratory, especially compared to "cookbook" laboratory experiences. Similarly, Bowen et al. (2017) criticized what they called recipe types of chemistry laboratory experiences for students. More recently, Brinson (2017) analyzed recent research related to student learning outcomes in remote and virtual laboratory experiences compared to traditional, hands-on science labs. However, he found that very little research had been done in relation to remote and virtual chemistry laboratory experiences compared to studies in other natural sciences such as physics.

As chemistry education changes, so do the demands on assessment. Chen, et al. (2013) describe assessing students' laboratory skills using a rubric. Laboratory skills are often a learning outcome for laboratory based natural science courses, especially in general education course work. The *National Science Education Standards* (National Research Council [NRC], 1996) addressed the issue of improving learning in the science laboratory. Inquiry and problem-based learning (PBL) improve learning in the sciences, including chemistry. Hands-on, active learning experiences reflect the complex, dynamic and interdependent systems within chemistry (Mahaffy et al., 2019).

However, questions about how to replicate or at least simulate the hands-on laboratory experiences of chemistry courses online and/or remotely continue. Advances in laboratory simulations and virtual education may provide opportunities for remote learning in laboratory like settings. Brinson (2017) cited the difficulties related to creating realistic chemistry laboratory simulations as a reason for a lack of literature on remote chemistry experiences. Rivera (2016) suggests a hybrid of hands-on and remote laboratory experiences may be best.

However, this combination is not always possible if there is no means of F2F laboratory sessions. Yet active-learning experiences, rather than didactic instruction, can lead to challenges regarding assessments. In other words, informative and accurate assessments must reflect the abilities of students to perform exploration and experimentation as well as understanding of the chemistry (Chen, et. al, 2013) especially within the PBL environment. Similarly, the fuzziness of PBL experiences, from initial problem to demonstrated cognition by students, can be difficult to assess (Jonassen, 2000, 2011). Thus, innovative instruction can lead to assessment difficulties whether that instruction uses inquiry, PBL, or other techniques. The fact that many laboratories in universities are taught by graduate teaching assistants complicates the use of innovative teaching strategies (e.g. PBL) as well as different styles of assessment, such as rubrics (Chen, et. al, 2013).

Problem-based learning (PBL)

Problem-based learning (PBL) is a pedagogical strategy that encourages student-directed learning focused around solving a meaningful, open-ended, authentic problem with no set solution (Hmelo-Silver, 2004). Thus, PBL offers students the opportunity to think like discipline experts as they approach the problems within their domain (Jonassen, 2000). This is similar to Walker's (1961) suggestion that general education course work should focus more on the methodology of the discipline rather than broad, comprehensive coverage of topics. Although the medical education community initially adopted PBL, its use has expanded into K-20 education (An, 2013; Barrows, 1996). The PBL design is meant to facilitate students' deeper learning of the content (Jonassen, 2000, 2011) and is based on Vygotsky's (1986) social construction of knowledge. However, DeChambeau and Ramlo (2017) found that professional development is necessary to help those involved teaching with PBL especially in the early stages of implementation.

Within a PBL task, groups consist of five to seven students. Instructors provide students with a small amount of information regarding the situation. Not all of the information is available at the start of the problem (Hmelo-Silver & Barrows, 2008). The initial information provides for an ill-structured problem. Thus, in PBL experiences, students work collaboratively in small groups to determine what information must be collected, the design of their data collection, and the presentation of problem solutions. In other words, the goal of using PBL is for students to know how to *apply* their knowledge rather than simply to *remember* information (Bodner & Herron, 2003). Although PBL experiences are typically face-to-face, Ng et al. (2014) envisioned and executed a PBL that was done with students online. They detail the benefits and flexibility of an online/remote PBL experience, although this experience is related to speech and hearing rather than a natural science. Yet, whether face-to-face, online, virtual, or remote, PBL groups must possess a sense of collective responsibility (Hmelo-Silver & Barrows, 2008). Additionally, it is important to provide PBL experiences that fit the levels of the students (Jonassen, 2011).

Similarly, Hofstein and Lunetta (2004) describe the phases of any inquiry-type experiment. This PBL experience also includes the following phases: pre-inquiry, inquiry, and the experiment planning. Thus, PBL, including the CFE experience described here, involves students engaging in higher levels of learning skills. Additionally, within this type of experience, students are likely to explore their metacognitive abilities (Bodner & Herron, 2003; Hofstein & Lunetta, 2004). Consequently, students may develop skills within this CFE PBL experience that will be beneficial throughout their non-STEM degree earning process. In summary, PBL offers a means of improved teaching and learning of chemistry (Bodner &

Herron, 2003). Improved learning of chemistry, within an authentic and team environment, represents the initial impetus for including PBL within the CFE laboratory.

Student Groups

PBL requires students to work effectively in small groups (Jonassen, 2011). In most general education natural science courses, the laboratory offers the opportunity for students to work in small groups, typically groups of 2 to 3 students. These laboratory groups provide multiple opportunities for productive interactions among students, as well as with the instructor. Students often view this as a positive and social learning environment (Hofstein & Lunetta, 2004). However, students may focus on the social aspects of group work rather than its effectiveness for learning (Ramlo, 2015).

Teamwork is applicable to any undergraduate major at the university and is an essential element within any PBL experience (Jonassen, 2011). When students work in groups, they must explain and justify their positions, which, in turn, results in reflective social discourse (Land & Zembal-Saul, 2003). Yet teamwork requires students to use (and possibly develop) soft skills such as effective communication (Miller & Sundre, 2008). Sridharan and Boud (2019) stress that peer feedback is an important aspect of students working in groups. When it is effective, peer feedback leads to enhanced teamwork behavior and self-assessment ability. Oakley, et al. (2004) offer suggestions to make student groups work as effective teams. Oftentimes, sufficient class time is not available to help students learn how to work effectively in teams. One of their suggestions is that instructors offer a peer rating system for teams. These ratings would then be used to adjust group grades for individual performance. Oakley et al. (2004) also suggest offering a series of forms for students throughout the project timeframe in order to structure input and provide a framework for teamwork development and effective team communications.

As we will discuss within the next section on laboratory design, effective communication and teamwork are skills highly sought after by employers of all employees, not just scientists.

Setting the Stage

Students often question the relevance of their general education course work and this includes physical science courses (Miller & Sundre, 2008). Authentic, relevant tasks are an important aspect of any science course (lecture and laboratory) to engage students in their learning. Chinn and Malhotra (2002) suggested that authentic, inquiry experiences should become a priority in every science course. Their suggestion is in alignment with the findings of Miller and Sundre (2008) regarding relevance of material and topics within general education course work. Thus, a major goal of this project was to set up an authentic chemistry experience for students in CFE. The instructors structured the problem such that it was clear that students had to demonstrate the following characteristics within their teams: effective organization, teamwork, effective communication, self-direction, and strong problem-solving skills. Therefore, the instructors created the problem situation as happening within a company where each student group made up a different research team. In this way, students would not be operating in the usual "academic" type of environment where the instructor provides a series of deadlines and must remind students of various details related to a laboratory experience.

Laboratory Design

The PBL laboratory experience was designed based upon the literature as well as the authors' extensive teaching experiences and prior student interactions. Within this section, we describe the various aspects of the laboratory design. Detailed descriptions are included to allow others to replicate this type of experience in their chemistry, or other physical science, courses that serve as general education natural science courses for non-STEM majors.

To foster the appropriate setting for this project, the lab instructors constructed the PBL-manual professionally such that the manual appeared 'official' and was spiral bound. This manual consists of an introduction that describes how the group of students are forming a research group within the company. Each group received specific objectives for them to demonstrate by the end of the project. The PBL-manual also included a table of key chemistry terms with definitions for the lab PBL experience that would also be helpful for the lecture portion of the course. Finally, the PBL-manual contains a required timeline and four student contracts, discussed later within this section.

Introducing the Problem

The lab instructors introduced themselves within each laboratory session as the company presidents. As the company presidents, the instructors stressed the need for effective communication among the students within the PBL experience (research group) and that each group member was expected to perform their duties. Creating the student teams as research groups within the company helped create the sense that although the students had collective responsibility for their problem, they could also go to the instructors (company presidents) if there were personnel types of issues or if a member dropped the course. The instructors also indicated that waiting until the last minute to ask the "presidents" for help with coworkers or other issues was not an option.

Additionally, instructors provided students with a brief introduction to the PBL problem and setting. The instructors provided students with a list of the five company roles that included descriptions. Team members negotiated amongst themselves about their respective roles within the team. These roles are Scientist, Engineer, Safety Officer, Marketing Manager, and Secretary.

As students selected their roles, the group's Secretary picked up the official spiral-bound PBL-manual, which was also made available on the laboratory's online course management system (Desire2Learn). Company presidents (instructors) handed the spiral-bound PBL-manual to each team's secretary in a ceremony.

Student Roles

As mentioned above, there were five different student roles within each student research group. Although there was only one scientist, the expectation was that, as Land and Zembal-Sault (2003) explained, each group's students would be expected to explain and justify the group's procedures and decisions, regardless of their student role within that group. In other words, every student was expected to be able to explain the chemistry within the PBL as well as other aspects of the experience. The desire was to create a situation where reflective social discourse was routine.

The five member roles are Scientist, Engineer, Safety Officer, Marketing Manager, and Secretary. Most groups consisted of five students, one for each role. In the case of a group with six students, there were two Scientists. The following provides a description of each of the group roles:

Scientist – This person is responsible for gathering the information concerning the PBL's chemistry. They are also responsible for ensuring the other members understand the required chemistry. The Scientist will provide the literature related to the PBL and write the experimental procedures.

Engineer – The Engineer will investigate how this PBL prototype lab can be scaled up to produce a larger amount of product and would involve input from the Scientist and what they had learned about the chemistry of their chosen lab experiment. This scale-up might require additional equipment and glassware, for instance, and the role of the engineer is to ascertain what these requirements will be. The Engineer will need to produce calculations for this scale-up including, potentially, calculations for reagents and yields. The Engineering will provide literature that relates to any of the chemicals or procedures used in the experiment.

Safety Officer – All members will work with the safety person to maintain a safe work environment. The Safety Officer will provide the SDS (Safety Data Sheet) for each chemical used within the PBL. The Safety Officer will provide the information concerning each chemical's "chemical diamond," proper handling, and proper disposal. The Safety Officer is responsible for detailing required safety equipment and ensuring that all scientific endeavors associated with the PBL meet safety requirements. The Safety officer will need to locate professional articles concerning chemical spills and other associated safety protocols.

Marketing Manager – The Marketing Manager will need to work with the other group members especially the engineer and scientist who will provide the lists of chemicals and equipment required. The Marketing Manager will select the vendors and report costs for these chemicals and equipment. For the scale-up, the Marketing Manager and the Engineer must collaborate to determine the cost of the scale up. The Marketing Manager will also investigate the targeted consumers for the product along with a rationale. The Marketing Manager will determine if there are similar products for sale, FDA considerations, animal testing, or other requirements.

Secretary – This person is responsible for setting up meetings, keeping the group on track, sending reminders, getting all information from group members to compile into the formal lab report, and getting all information from group members for compiling the final presentation. Yet, we expected that students would struggle within their groups as they negotiated meaning and cooperative interactions. Thus, safeguards were created to help students effectively work together, and these are primarily within the four contracts required for the PBL.

The PBL Contracts

A schedule for the laboratory is included in Appendix B. This schedule includes the standard laboratory activities run as well as the schedule for the four contracts that helped guide the PBL experience. These contracts are aligned with the team-development structure suggested by Oakley, et al. (2004). Within Contract 1, each team selected one product from a list. The product lists include a brief procedure and list of common chemicals (see Appendix A). The instructors selected simple products (with simple procedures and common chemicals) so that team members could potentially perform the experiments at home for friends, parents, or siblings. Thus, the PBL activity could be expanded to sharing the applicability of chemistry and chemistry knowledge beyond the PBL laboratory experience.

Within this contract, students provide their contact information and role assignments. There is also a detailed agreement for them to sign that describes how full cooperation, and communication of all group members is essential for the success of the PBL experience. In other words, the students are agreeing that it is not acceptable for another group member to pick up the work of someone that is slacking, and that reporting this to the instructor/president is part of good communication in an authentic company model.

Contract 2 is a document that describes the criteria required for researching and constructing the formal lab report as well as defining the student roles. This contract requires the team to meet outside of lab time to discuss the project. Contract 2 also stipulates that each group member must provide at least one research citation and document. This contract also stresses the need for using proper citations and the university's code of student conduct regarding plagiarism.

Contract 3 contains the rubric for the formal lab submission (discussed further within the assessment section) with emphasis on the importance of all contracts being submitted fully on time for the instructor to review before being allowed to perform their lab. This contract stresses that even if the group receives zero credit for missing a contract deadline.

Contract 4 is the rubric (see Table 3 within the assessment section) for the group presentation. This rubric includes a requirement that students must equally share in the presentation within their individual roles. Each student must describe how their job fit into the structure of the company and its success. Thus, a requirement within Contract 4 is demonstrated teamwork. The presentation guidelines also emphasize that everyone is responsible for being prepared to answer any question posed by the instructor regarding the chemistry involved in the PBL. Instructors provided the student teams with a Power Point presentation form to be completed. This form included slides specified for each student role such that the presentations would be equitable amongst the group members. It is important to note that the presentation grade is not an individual score. If the presentation has reduced points because one member did not fully participate, each group member will get the group grade. Therefore, it is essential that team members communicate and discuss any issues with those team members not working properly immediately rather than waiting until the end of the PBL experience.

Company Products

The students selected the lab product for their research group from a list provided by the instructors. The lab product choices were not constricted by what other groups selected. In other words, it was possible that the nine student groups could choose the same lab product for their research group. However, the instructors stressed that plagiarism included using other group's work (data, presentations, text) and that this would not be tolerated. Additionally, in the case of multiple groups selecting the same lab product, the instructors would judge formal lab reports and presentations against the others with the same products.

The instructors were cognizant of Jonassen's (2011) suggestion that, in PBL, it is important to provide problem cases that are fitting to the levels of the students. Thus, the lab procedures offered to students were not complex, did not require specialized chemical laboratory space (e.g. fume hoods), and could be replicated at home if need be. The procedures were simple enough that students could design a product; such as a home chemistry kit for kids or a do-it-yourself soap making kit. However, the procedures/products offered provided the means for students to learn about many different chemistry concepts and applications including, but not limited to, Lewis dot structure, bonding electrons, intermolecular interactions, intramolecular interactions, and stoichiometry. Yet, within this PBL, students will explore these topics and more within an authentic setting. Additionally, within the setting of a research lab, students had the opportunity to apply other skills including communication, marketing, and technology. Instructors provided a basic sketch of each lab product, including basic materials and procedures, within the PBL-manual. Within their research group roles, procedures for experimentation and safety were to be developed.

The lab procedures offered as choices for there were:

1. Milk rainbow
2. Designer soaps
3. Slime
4. Sugar snake

Each of these products allowed for exploration and experimentation. Although all four of these represent elementary school types of science experiences, here the students are expected to explore, observe, and experiment as well as investigate the chemistry involved at an undergraduate student level. These products were also meant to help keep students from feeling intimidated. Appendix A contains more information about these products within tabular form. These tables include the goals for each product and the initial chemical information (chemical list and procedural starting point) provided to students.

Constructing the Laboratory Document

Together, the group compiled their Laboratory Document. Unlike a typical formal lab report, students wrote this document as if they were creating a laboratory activity for students (the type many general-education chemistry courses offer to students, written by instructors). This lab document included pre-lab questions (with answers), a detailed theory section (including related chemistry), objectives, equipment list, chemical list, experimental procedures, and lab safety. The document also included a section with all relevant data (including observations, graphs, and tables), calculations, and results.

However, the lab instructors were actively involved with students while they created their procedures and other aspects of the Laboratory Document. As company presidents, the instructors routinely asked students during lab time for updates regarding their progress on the PBL experience. This helped to make the situation more authentic and enforced the idea that the PBL teams were acting as a company's research group. Within PBL, instructors must be actively engaged with students as they facilitate student learning. The instructors had a guideline of inquiry that included questions about the team's process, contributions, chemistry, and difficulties. As graduate level chemists, the instructors could also anticipate problems and address them with the students.

Finally, students must include a conclusion within their final document where findings are supported with evidence (data and/or calculations) as well as post-lab questions (with answers). The conclusion may also include reflections on procedures or other aspects of the PBL experience that would improve the product, safety, or other aspect of the lab product. Once the instructors approved the laboratory document, the student team turned in the finished document to the instructors. The instructors ran a final check regarding thoroughness and safety issues prior to providing permission for the team to perform their lab experiment the next week.

Group Presentation

Each group presentation consisted of 20-30 minutes for the presentation and 5-10 minutes for questions from the instructors as well as students, if they desired. The instructors provided a semi-structured Power Point form for the student groups. The structure promoted a standard format but also facilitated having each student present for a similar amount of time. Part of the structure included introductions at the beginning of each presentation by each student-employee stating their name and role. Additionally, each participant reported on something they found either interesting or difficult related to this PBL project. Each student-employee demonstrated their contributions with pictures. Proper citations were required for all information. Student teams presented data and results within tables and graphs. Each group member had to demonstrate the ability to answer chemistry questions related to the product and its development. Although instructors primarily asked questions, students were encouraged to ask questions of the presenters with a focus on the laboratory procedures and design of the product.

Assessment of PBL Experience

In the CFE course, there is a combined lecture and lab grade with 50% of the grade determined from lecture assessments and 50% of the grade determined from the laboratory assessments. The lecture portion consists of homework, quizzes, and exams. Recently, to address the mandated learning outcomes for natural science general education courses at the university, the lecture instructor added an essay component to the assessments contained within the lecture portion of the course. More specifically, these essays address the written and oral communication requirement for natural science general education course work. At the university, assessing writing across the curriculum has been problematic, especially within the natural sciences. These two essays are intended to encourage students to read scientific articles and draw connections between current events/research and topics discussed within the lecture portion of the course.

In previous iterations of the CFE course where lab met twice a week, students completed 25-27 separate laboratory activities over 15 weeks. The selection from 35 total laboratory experiments is CFE course lecturer dependent. Within this laboratory revision, students completed the PBL project, which represented 30% of the overall laboratory grade (all aspects of the project). Additionally, students were to complete 21 laboratory activities. The CFE laboratory met twice a week for 1.5 hours each. The traditional laboratory activities represented 70% of the overall lab assessments.

For the PBL experience, some points were associated with completing the company contracts (e.g. Contract 1 was worth 5 points for each team member). Students could earn up to 10 points in relation to Contract 2. These points included students setting up a meeting with their group about their PBL activity progress and listing the citations they had compiled at this point.

Grading of the Laboratory Document is based upon a rubric provided by the instructors (within Contract 3; see Table 1). This rubric provides a point distribution for the various parts of the Laboratory Document yet was kept rather simplistic.

Table 1

Laboratory document rubric

Item	**Received points**	**Possible points**
Introduction page including all group member names and their roles		1
1.5 line spacing with 14-point Times New Roman font		1
Professional looking; formatted tables, pictures, chemical structures and/or molecules. All major headings included – prelab, introduction, equipment and chemical list, safety, procedure, data and/or tables, post-lab, and modifications page. Header with experiment name and footer with page numbers.		8
Formal and detailed Introduction (1-2 pages typed 1.5pt spacing, not including diagrams, figures, or pictures). Each member should clearly contribute and show citations.		20
Pre-lab and Post-lab questions and answers (included, relevant, and answered correctly)		10
HANDED IN ON TIME (= 10 points); Late but before the last lab day of week 9 (= 5 points); After this date (= 0 points). Note: Groups cannot perform their lab without a complete lab and contracts 1-3 handed in.		10
Week 10 complete the lab and hand in the data report		10

The presentation stage of the PBL experience is worth a maximum of 75 points. Instructors scored each presentation using a rubric as well. Students receive a group grade for the presentation rather than individual scores. This rubric is shown in Table 2, below.

Table 2 |

Rubric for student team presentations

	5 points Exemplary	4 points Good	3 points Satisfactory	2 points Some issues	1 point Included but unsatisfactory	0 points Not completed / included
Each member introduces themselves and their role as well as at least one detail about the project or something new they learned about their job that was interesting to them.						
Members demonstrate how they contributed as part of the presentation. (you should not just read off the slides or index cards) Each slide should contain some kind of relevant picture and written information.						
The presentation was given in a professional manner (though chemistry jokes are always fun) that discusses the chemistry behind the experiment and relevant chemical information. Each slide should contain the citations for the information. This should teach the class something interesting.						
Each group member answered the questions asked by the instructor to their satisfaction.						
The presentation was within the time limit; each member spent about 3-5 minutes for their part of the presentation.						

Discussion

Within this section, the authors discuss the future iterations and adaptations of the chemistry PBL, including the influence of the pandemic on the original plans. This was the first PBL experience designed by and taught by the two graduate teaching assistants who instructed the CFE laboratories. Student feedback about their PBL experience was primarily positive. Many students particularly enjoyed their role within the larger project. One group struggled with their collaboration due to some negative group dynamics and problems with equitable student contributions to the PBL. However, in other groups, the students felt that being part of a group helped motivate them to do their part well. Most students shared that they enjoyed the collaborations within their groups. The opportunity for human interaction may have become especially important due to the pandemic. As Hofstein and Lunetta (2004) suggested, students enjoy the social interactions of PBL experiences. However, improvements to the group interactions and contributions are something that will need to be addressed within this PBL experience in the future. The pandemic's influence on the various aspects of the PBL, however, cannot be ignored.

COVID-19 Influence

This PBL experience was planned for spring semester 2020. In the middle of week 9 of the semester, the university administration closed the university and began spring break, 1.5 weeks early. The next 2.5 weeks were filled with faculty preparations to move all of their formerly face-to-face courses and laboratory experiences online. The graduate student instructors had to create new online pre-lab quizzes with videos. The remaining six CFE labs were converted to virtual learning documents and video such that students had to garner important information from their laboratory manual to complete the necessary calculations. Thus, the traditional laboratory activities were no longer hands-on or even laboratory based.

Within this context, the instructors were especially well prepared with the PBL activity. Students had already formed their groups and had begun their literature research and experimentation. Writing the Laboratory Document continued with input from the laboratory instructors carried out electronically. Instead of presenting their experiments F2F with the other students and instructors, during the laboratory time, students performed their presentations via WebEx. Because of safety considerations, students did not perform their experiments. The fact that students had to maintain social distancing while completing the Laboratory Document and the development of the laboratory procedures influenced this decision. Instead, the student groups had to develop procedures and safety criteria such that one of the instructors, with assistance from her children, could run the laboratory experiments based on students' documentation. These laboratory experiments were recorded for students. The instructor provided the video and feedback to each student group. Students were to observe the video and consider the feedback before creating their group presentation via WebEx.

This change within the original PBL design allowed the instructors to test the quality of the students' procedures and safety protocols. The instructors wanted to eliminate issues related to the inability for the student-team members to physically work together to run the PBL experiments. These changes also required a revision of the original rubric for scoring the presentation since certain key components changed with the move online / remote. The instructors were disappointed but were able to create a better learning experience than what was done in other laboratory activities where either students simply received data from their instructors and/or the instructors / graduate students videoed running the laboratory activities and posted those videos on the learning management system. The PBL allowed the CFE laboratory instructors to preserve some active learning for students within this context. Other lessons were gained as well.

Video presentation option

In the future, we would maintain the idea of students creating a video of the group performing their experiment(s) and presenting the other aspects of the PBL presentation. Within the post-COVID-19 future, students could collaborate in close proximity to each other while doing experimentation and honing their product, procedures, and safety protocols. Yet the idea of creating a video and posting it to the online learning management system has many benefits that were realized during the coronavirus hiatus from campus. During a regular semester, video presentations would save time during the final instructional weeks of the semester. Additionally, with this flexibility, students could better fine-tune their experiments during those last weeks of the semester, within the laboratory and during the lab time. This would be more productive than using that lab time for presentations. Another benefit of videos is that it is easier to compare presentations on the same company product and to police potential plagiarism.

Secretary renamed administrator

With instruction moved online, the secretaries on each team struggled to have their team-members turn in their assignments in a timely manner. Several students in the role of Secretary complained to the instructors that they felt texting and emails were less effective in coercing students to hand in their work than the ability to confront these students face to face. These secretaries requested advice from the instructors about how to address this situation and problem-solve these management issues.

This has led to another suggested improvement - the Secretary role should be renamed Administrator simply because the term secretary seems out of balance with the rest of the roles offered to students. This role is a pivotal one for the student-teams and the title and list of duties should better reflect these ideas. Thus, "managing" the team more effectively while also maintaining records of students' time on the project should be added to the duties of this role. Because of issues related to student contributions to their teams, conversations between the students and student-secretaries led to the idea of "timecards" for team members. These "timecards" would then be part of the final laboratory document. A secure, electronic means of keeping track of student time would be best. We admittedly see the equitable teamwork as an issue that is not easily addressed, but this could be an option for tracking time on the PBL experience.

Expanding chemistry into other team roles

Additionally, it appears that those who assumed the role of Scientist may have held too much responsibility for learning and teaching to their group peers any chemistry involved. Although the instructor questioning of all student team members regarding the chemistry of the product and chemical procedures was meant to address this issue, in hindsight we would probably create more connections between some of the other team roles (especially Engineer) and investigating the chemistry involved within the group's chosen product and experimentation.

Considering Individual Performance

Issues pertaining to fair work distribution among students within their team were not easily resolved even when the instructors became involved. This led us to examining the literature more closely about group projects of any kind. Certainly, a PBL experience does create issues related to assessment as Jonassen (2000, 2011) mentions, especially in relation to cognition. It seems that providing split grades (team and individual) for the Laboratory Document and Experiment-Presentation is a possibility. In this way, students would receive both a group-grade and an individual-grade for both the Laboratory Document and the Experiment-Presentation. Alternatively, consideration should be given to the suggestion by Oakley, et al. (2004) to incorporate peer-rating system for the student-teams that offers a standardized procedure for using these ratings to adjust group grades for individual performance. In other words, we need to improve the design and management of these team assignments within the context of the PBL experience.

Improved assessment

In addition to differentiating group-grades based upon individual contributions to the PBL, we believe that other changes to the assessment of the various aspects of this PBL experience is necessary. As Chen, et. al, (2013) explain, informative and accurate assessments must reflect the abilities of students to perform exploration and experimentation within the context of understanding chemistry. For instance, the rubrics should provide more detail, with a more explicit breakdown of points. As an example, within the Laboratory Document rubric (Table 1), an item states the following is worth 20 points: Formal and detailed Introduction (1-2 pages **typed 1.5pt spacing**, not including diagrams, figures, or pictures). Each member should clearly contribute and show citations (see example). However, students were unsure about the details required as well as how the points would be distributed for this section. Therefore, the following would be offered as a revised item within this rubric presented in Table 3.

Table 3

Revised rubric criterion for "Theory in paragraph form"

Section	Description	Points
Theory (in paragraph form)	i) Includes proper description of all chemistry related to the product (+10); key chemistry idea is missing (+5); these aspects are limited (0-4) ii) Correctly **describes** all major aspects of **theory/principles**[1] ASSOCIATED with product beyond what is contained in the PBL-Manual = +10; 1 key principle or theory missing or limited to manual text = +5; More than 1 missing = +4-0;	20 maximum

[1] A scientific theory is a well-substantiated explanation of some aspect of the natural world that is acquired through the scientific method, and repeatedly confirmed through observation and experimentation. It is more than an equation. It is not the same as a hypothesis or experiment objective.

Additionally, rubrics should focus on the PBL processes used by students instead of the end products like the report and presentation.

Learning outcomes

Finally, in an attempt to align CFE with the university's newer natural science general education requirements, the CFE lecture instructor has included an essay requirement to the CFE course assignments. Within this PBL, the natural science general education requirements for written and oral communications were met via the Laboratory Document and presentation. Additionally, the PBL experience addresses the stated goal of the essays to have students read and cite the current chemistry literature. Thus, this more meaningful and authentic experience could and should replace the essay requirement as described earlier within this manuscript.

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APPENDIX A – COMPANY LAB PRODUCTS

The lab procedures offered as choices with the same details contained in the lab PBL-manual are provided in the tables below:

Table A | Milk rainbow

Product	Milk rainbow
Possible applications	Children's chemistry kit; Party games
Basic Chemical List	Milk, dye, dish soap, cotton swabs, and shallow bowls / plates.
Basic procedure provided by instructors	Pour milk into container to about ¼" and let sit a few minutes. Add 2-4 drops of coloring to the milk that don't touch each other. Touch the center of the milk with a clean Q-tip and observe. Dip the opposite end of the cotton swap in dish soap. Place soap end into center of milk for 10-15 seconds. Dip another cotton swap in soap and touch milk in various areas. Record observations. Repeat this with variations of 3 other milk and soap products.
Goal	Students will be able to explore surface tension, polar vs non-polar, hydrogen bonding, statistical data, molar mass, density, experimental design, organic functional groups, and molecular bonding.

Table B | Designer soaps

Product	Designer soaps
Possible applications	Boutique shop; Home business
Basic Chemical List	Sodium hydroxide pellets, distilled water, coconut oil, castor oil, olive oil, and scent (optional).
Basic procedure	Weight out 55g of sodium hydroxide pellets into a beaker. Place 150mL DI water into a 250mL beaker. Slowly add and stir the sodium hydroxide pellets into the

provided by instructors	water over a 15-minute period with mixing. Keep mixing the solution with a glass-stirring rod until clear. The solution should be cooled to ~45C. In a 400mL beaker weight out 80g of coconut oil, 20g castor oil, and 300g Olive Oil and warm until solids are melted and cool to a temperature of ~45C. Without heating, pour the sodium hydroxide solution into the oil mixture and start whisking. It may take up to 30minutes for the soap to start to thicken. Keep mixing and be patient. When you see it thick enough to leave peaked lines, you can add some scent and mix. You should take about 5-6 reading for pH with pH paper over the course of thickening. Pour soap into the molds provided. Put a few dots of color on top and use a glass stir rod to swirl the color within the mixture. These will need to sit until the next lab period. You should take one "bar" of soap and do further testing for soap like appearance, lather, pH, etc.…. You should test another "bar" before you do your presentation (you can find a couple of minutes during another lab time for testing).
Goal	Students will be able to explore exothermic vs endothermic, polarity, ionization, hydrogen bonding, molar mass, density, molecular bonding, experimental design, molecular geometry, stoichiometry, saponification and general organic chemistry.

Table C | Slime

Product	Slime
Possible applications	Elementary school science experience kit; Party games for kids
Basic Chemical List	Tetraborate, distilled water, PVA
Basic procedure provided by instructors	Stir 5g of sodium tetraborate into 250mL of warm DI water. Place 100g of PVA in a beaker with 100mL of water, add coloring and stir. Slowly pour borate mixture into the PVA mixture. Once a solid large "glob" is formed, you can scoop it out with your hand and knead it. Does kneading make a difference? Repeat the experiment 2-3 more times with variations on the amount of borate and/or DI water then record observations.
Goal	Students will be able to explore polarity, hydrogen bonding, molecular bonding, molecular geometry, molar mass, experimental design, density, and stoichiometry.

Table D | Fire snake

Product	Fire Snake
Possible applications	Elementary school science experience kit; Party games for kids
Basic Chemical List	Baking soda, sugar, sand, isopropyl alcohol, lighter, and ceramic dish.
Basic procedure provided by instructors	In a small beaker, mix 4 Tablespoons of sugar with 1 tablespoon of baking soda. In a dish, pack sand well and make small depression in middle. Pour some isopropyl alcohol on the sand and in the middle. Pour sugar and baking soda mixture into middle. Light the sugar and baking soda mixture. Vary the experiment; observe what happens with just sugar or just baking soda. Explain all observations and weights.
Goal	Students will be able to explore the combustion reactions, ionic vs covalent bonding, exothermic vs endothermic, experimental design, hydrogen bonding, molecular bonding, molecular geometry, molar mass, density, stoichiometry, and organic functional groups.

APPENDIX B – LABORATORY ASSIGNMENT SCHEDULE

Week	Days	Experiment number and Topic	PBL Due Dates
1	Tuesday	1 Lab safety & Common Techniques	
1	Thursday	3 Taking Measurements	
2	Tuesday	4 Percent Water in Popcorn	
2	Thursday	5 Structure, Energy and Chemical Changes	
3	Tuesday	6 Atoms Emitting Light, Bohn Atom, Electron-Dot Structures II	
3	Thursday	7 Properties of Bond Types	
4	Tuesday	8 Atoms Compete for Electrons to Form Bonds: Electron-Dot Structures II	
4	Thursday	9 Molecular Shape and Polarity Are Due to Electron-Electron Repulsions	
5	Tuesday	10 Types of Chemical Reactions 11 The Mole: Counting Atoms and Molecules	Contract 1
5	Thursday	\ (Exam 1 – No Lab)	
6	Tuesday	\ (President's Day – No Lab)	
6	Thursday	12 Freezing Cooler, Boiling Hotter, Entropy in Rubber Bands	Contract 2
7	Tuesday	13 Properties of Acids & Bases	
7	Thursday	14 Neutralization Reactions	
8	Tuesday	16 Properties of Gases	
8	Thursday	18 Quality of Drinking Water	
9	Tuesday	19 Chemistry Occurs When Electrons Move: Batteries and Fuel Cells	
9	Thursday	20 Properties of Organic Solvents	Contract3
10	Tuesday	23 Making a Hand Sanitizer	
10	Thursday	\ (Exam 2 – No Lab)	
		\ (Spring break – No Lab)	
11	Tuesday	21 Partitions and Candy Chromatography	
11	Thursday	26 Fossil Fuels, Biodiesel, Calories in Foods, and Heats of Reactions	
12	Tuesday	32 Isolation of Natural Products: Proteins	
12	Thursday	Lab design	Lab Design
13	Tuesday	29 DNA Capture	
13	Thursday	28 Synthesis of Aspirin	
14	Tuesday	Optional lab "makeup"= lab final exam	
14	Thursday	PBL Presentations	Contract 4
15	Tuesday	PBL Presentations	
15	Thursday	PBL Presentations	