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The Chemistry Laboratory Experience of El Camino Students While in Emergency Remote Teaching Due to the COVID-19 Pandemic

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THE CHEMISTRY LABORATORY EXPERIENCE OF EL CAMINO STUDENTS WHILE IN EMERGENCY REMOTE TEACHING DUE TO THE COVID-19 PANDEMIC

A dissertation submitted in partial satisfaction

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by

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DOCTOR OF EDUCATION

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DEDICATION

Dedicated to my wife, without whom this would not have been possible.

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Finally, to my grandpa—see? I'm finally done being a professional student. Final degree here, thankfully, though I'll never stop learning.

VITA

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ABSTRACT

Future college environments, including those in chemistry, will entail flexible formats. The pandemic spurred appreciation of the need, and though it has largely passed, adaptability to multiple formats in the future has been a critical part of planning for a rapidly changing future. Experiences during the pandemic will guide pedagogical changes and practices in the future.

At El Camino College in Southern California, the chemistry department provided varied laboratory instruction to students during Emergency Remote Teaching. Understanding the experience students had during this extraordinary time is essential. Students who took courses that had an online laboratory course completed a mixed-methods survey. The survey consisted of a new tool designed for the study (Inquiry Rubric Tool), one used previously in the literature (Meaningful Learning in Laboratory Instrument), and a series of qualitative questions.

Results of the complete survey showed that most students experienced low levels of inquiry and lower levels of meaningful learning compared to the literature during their online laboratory assignments. In addition, levels of inquiry showed a negative correlation when compared to affective, cognitive, and cognitive/affective scores derived from the survey. Levels of confusion and frustration were high. Poor quality materials, lack of hands-on activities, and lack of instructor presence were common. Some positives were noted regarding the ability to repeat experiments online and the flexibility of performing experiments when students wished. Students indicated interaction with fellow students during ERT as important. Suggestions for policy change, including synchronous work and hands-on activities, are made to invoke policy change at El Camino College in case of future ERT or further online chemistry course curriculum development.

Chapter 1: The Problem

In the spring of 2020, the global pandemic swept the education system in the United States. Instructors were forced to cancel their classes or move into Emergency Remote Teaching (ERT). While this affected everyone in education, it also provided a unique opportunity. Courses such as chemistry, which were taught only in face-to-face and hybrid format, were subjected to a complete remote setup. The American Chemical Society has stated that a hands-on experience is essential to learning chemistry (ACS Guidelines, 2015). For once, chemistry students and instructors on a broad scale were compelled to learn at a distance with the possibility of no hands-on experience. Understanding their experiences can be exceedingly beneficial to the chemistry education community at large. The following section will contextualize this issue by introducing chemistry education and the COVID-19 pandemic. Chapter 2 will discuss the many ways chemistry educators responded to this crisis.

The COVID-19 Pandemic

Hodges et al. (2020) define ERT as a temporary remote alternative to the usual teaching delivery system. While ERT is not meant to replace a current system, it is intended to maintain a moderate level of education and rigor. By defining ERT, learners and educators can "divorce it from 'online learning'" (Hodges et al., 2020, p. 11). In other words, ERT is unique from a typical online learning environment.

When the COVID-19 virus struck the world, many institutions moved to ERT. At its peak, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) stated that 90.1% of enrolled students were affected in some way by the closures. In the early part of 2020, Chavez and Moshtaghian (2020) reported that 48 states and the District of Columbia had instituted school closures for the entire academic year or at least recommended it. The National Conference of State Legislatures indicated that 1,100 colleges across the United States were subjected to ERT during the pandemic (Smalley, 2020).

In the United States, the education system was not set up to deal with prolonged shutdowns (Dorn et al., 2020). Through statistical analysis, Dorn et al. (2020) further reported that the longer students are away from in-person learning, the higher the risk of significant learning loss. Students from disadvantaged backgrounds have a higher risk than others for learning loss (Dorn et al., 2020). As of December 2021, the most recent statistics (October 21) counted 48 million students affected by full school closures and 704 million students affected by partial closures (UNESCO, 2021). Many students remain in ERT almost two years later.

Students and instructors in the ERT situation had many difficulties to overcome. Cramman et al. (2021) noted that students had trouble finishing laboratory research remotely, and instructors were required to redevelop course materials. Yet, the course objectives could not be changed during this time. There was not enough time to do so. Students suffered due to overly large online classes. Large classes buck against research-based teaching wisdom. Burch (2019) stated that for an online course to be effective, class sizes should be between 8 and 20. Many chemistry classes have much higher student counts than recommended by Burch. Instructors often carried over the same size classes from face-to-face to the ERT situation. Large class sizes meant less individualized attention per student, which is especially necessary during remote learning.

The situation challenged chemistry instructors and students. Kolack et al. (2020) reported difficulty teaching online for extended periods, seated in front of their computers, and felt stressed due to the physical demand of doing so. Technical challenges during ERT were also common, with students reporting internet issues, procuring and using equipment, and the use of new materials and tools (Aguirre & Selampinar, 2020; Burnett et al., 2020;

Giri & Dutta, 2021; Kolack et al., 2020; Kyne & Thompson, 2020). For example, Aguirre and Selampinar (2020) reported that students had extreme difficulty learning and using Excel in data computation experiments. Further, Aguirre and Selampinar (2020) relayed that a student review noted that instructors often created an unproductive environment as they struggled to learn the tools they were trying to teach. Increases in academic dishonesty were also noted (Burnett et al., 2020; Donovan, 2020; Rupnow et al., 2020). Kalman et al. (2020) wrote that students reported higher levels of distraction, lack of motivation, and lower student attention spans during ERT. Burnett et al. (2020) noted that some chemistry instructors outright hated the online experience.

These experiences dealt with the online lecture component – something already done in chemistry via hybrid classes. The real difficulty came in converting the hands-on laboratory component of chemistry. Kolack et al. (2020) noted that their students often complained about their laboratory instructors. Students stated that their instructors were not engaged. Kelley (2021a) reported students performing hands-on experiments as having high affective ratings and engagement. The differences in student experiences regarding laboratory instruction in the ERT system are vast.

Emergency Remote Teaching Laboratories and Validation vs. Inquiry

When schools went to ERT, the chemistry community had to adjust their lecture and laboratories. This took many forms, including the use of virtual laboratory software, at-home hands-on chemistry experimentation, simulated experimentation, second-hand experiments, conceptual exercises, and some went as far as to cancel the laboratory portion of their classes (Kelley, 2021b). Reported experiences varied greatly.

George-Williams et al. (2020) reported that converting to an online laboratory system was the most challenging component of the ERT situation. The authors understood that their students could not do hands-on chemistry at home, so they moved to data explanation exercises, scientific writing, and discussion of techniques to compensate. Similarly, Qiang et al. (2020) reported difficulty converting to an online system for laboratory experimentation. The authors used a mixture of literature reviews, visualization of experiments, and simple home chemistry experiments. Huang (2020) performed a survey of chemistry students and instructors during the ERT situation in China. The survey results showed the primary challenge students faced was being unable to conduct experiments in teaching-labs.

Conversely, some literature reported relatively favorable laboratory experiences while in an online format. Howitz et al. (2020) submitted surveys at the middle and end of the semesters after replacing laboratory work with videos. Surveys were generally positive in regards to the video experience. The authors report a more moderate response when dealing with an electronic lab notebook (Howitz et al., 2020). Buchberger et al. (2020) reported positive student feedback when converting to an online remote teaching experience in the lab. The authors developed an online project based on inquiry where students worked through the development of an experiment. Students reported they enjoyed the flexibility of the project lab and working with real-world data.

D'Angelo (2020) stated that one of the most significant disruptions occurred due to a lack of hands-on laboratory activities. D'Angelo (2020) further noted that "no amount of mouse clicking or careful movements on a touchpad can replicate the "hands" required to add a reagent dropwise, spot a TLC plate, or turn the stopcock just enough to dispense fractional drops while titrating" (p. 3064). This means that instructors had to improvise to provide the best instruction possible.

Instructors had very little time to devise laboratory replacements. In many cases, something was better than nothing, and instructors lacked the time, energy, or resources to find quality replacements. Arnaud (2020) stated that even many hands-on experience kits given to students could be considered “cookbook chemistry.” Cookbook-style experimentation is also known as verification style laboratories, in which students follow a series of instructions and come to a known outcome (Domin, 1999). Tobin and Gallagher (1987) noted that this type of learning has a low cognitive demand. Others have derided this type of instruction as useless (Hofstein & Lunetta, 1982; Roth, 1994) with no meaningful learning outcomes. The author's experience is that cookbook labs are helpful for learning techniques but may not be the most powerful technique to use for linkage to theory.

Inquiry study laboratories better engage the student, allowing students to propose explanations in response to their gathered evidence (Martin-Hansen, 2002). The National Research Council (2000) defines inquiry as a study in which students must identify assumptions and consider alternatives to those explanations through critical thinking. Reports show that this type of learning is a more effective tool in educating chemistry and increasing student affective feelings, particularly in the laboratory (Chatterjee et al., 2009; Rudd et al., 2001).

The movement to online experimentation left instructors scrambling. Little thought may have been afforded to whether their experimentation was validation-based or inquiry-based. Both student and instructor experiences varied considerably across the reported literature. For the purposes of this study, the researcher will focus on the experiences of students and instructors of a single college, El Camino College, in Los Angeles County, California.

El Camino College

El Camino College serves a diverse population, with 52% reporting as Latino, 14% as African-American, 14% as Asian, 13% as white, 6% as Other, and 1% as Pacific Islander, with a total of 34,455 students in the 2018-2019 year. El Camino College went into ERT starting in March of 2020 (Haro, 28 Mar 2020). Beginning in the fall semester of 2021, students began to return to campus, though it was up to individual instructors if they continued ERT or not.

There are four semesters per year at El Camino College. The two regular semesters are sixteen-week courses held in the spring and fall. Accelerated summer and winter courses are offered for eight and five weeks each, respectively. El Camino College provides approximately 35 chemistry courses during the spring and fall semester and around twelve throughout the summer and winter terms. Every chemistry course in the course catalog has a laboratory component associated with it.

The standard chemistry series for science majors is five semesters long. It includes Beginning Chemistry (Chem-4), General Chemistry (Chem-1A and 1B), and Organic Chemistry (Chem-7A and 7B). El Camino College also offers health science major chemistry. This includes a standalone course called Fundamentals of Chemistry (Chem-20) and a two-semester course entitled Survey of General and Organic Chemistry (Chem-21A and 21B).

Most chemistry instructors declined when offered to return to in-person classes in the fall of 2021. Since ERT was initiated in March 2020, some students could have completed the entire chemical series off-campus. This places many students throughout the standard chemistry and nursing chemistry series at a potential disadvantage.

In addition to the unique problems students face during ERT, another factor affected student experience. El Camino chemistry department includes ten full-time tenure track faculty and fourteen part-time faculty. During the transition to online teaching, instructors had the freedom to choose how they wished to teach lecture and laboratory components. While there was some collaboration between full-time faculty, part-time faculty rarely participated in the discussion. This can result in wildly different online laboratory experiences, with some instructors using virtual labs, some attempting to use old data for computation, and others attempting new methods. These diverse instructor responses and their effect on student learning are the focus of this study.

Purpose Statement

This work aimed to evaluate the perceived learning accomplished by students during ERT at El Camino College. Efforts to understand the experienced level of inquiry and any link between it and meaningful learning were explored. In addition, it is the author's goal to understand students' overall experience concerning their laboratory work while the college was in ERT.

Research Questions

1. In terms of inquiry-based learning, what was the laboratory experience for students at El Camino College during ERT?
2. Is the overall level of meaningful learning experienced by students at El Camino College during ERT similar to published literature values?
3. Was there a link between the level of inquiry and the level of meaningful learning experienced by students at El Camino College during ERT?
4. What was the phenomenological experience for students in ERT laboratory exercises at El Camino College?

Hypothesis

- H_{o1}: There is no difference between the level of inquiry students experienced during ERT at El Camino College.
- H_{a1}: There is a difference between the level of inquiry students experienced during ERT at El Camino College.
- H_{o2}: There is no statistical difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature.

- H_{b1}: There is a significant difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values.
- H_{o3}: There is no correlation between the level of inquiry reported by students and the overall level of meaningful learning experienced in laboratory exercises by El Camino College students during ERT.
- H_{c1}: There is a positive correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.
- H_{c2}: There is a negative correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.

Hypotheses were chosen to best match the overall research questions.

Methodological Approach

The approach for this study was a mixed methodology as defined by Creswell (2014). Data collection in mixed methods includes both qualitative and quantitative procedures. In the case of this study, the approach was embedded, meaning the qualitative and quantitative data was collected simultaneously (Creswell & Creswell, 2014). In an embedded method, one of the two methods is considered primary. Using notation described by Morse (1991), the methodological approach for this research was QUAN-qual, where the quantitative data is primary and is supported by the secondary qualitative data. Qualitative data is meant to be complementary to quantitative data.

Quantitative data was gathered using a new tool created by the author based on the validation-inquiry rubric developed by Buck et al. (2008). Additional quantitative data was collected using the Meaningful Learning in Laboratory Instrument (MLLI) developed by

Galloway and Bretz (2015a). The first tool attempted to quantify the overall level of perceived inquiry students experienced during remote teaching. In contrast, the second measured meaningful learning concerning the cognitive and affective domains.

Qualitative data was gathered at the same time as the quantitative data. Questions were developed to investigate what techniques instructors used during ERT. In addition, qualitative questions aided in understanding the level of perceived inquiry, what students took away from the laboratory experience, and how they felt about the experience. Qualitative questions were open-ended to gather valuable, spontaneous, phenomenological data.

Limitations of Study

This work was a focused study; therefore, it has built-in limitations. The first limitation was that the survey was conducted at a single school, El Camino College. The second limitation was the population under investigation—those who took online chemistry courses at El Camino College during ERT. Students who took chemistry classes online at other schools during ERT were removed from the dataset before data processing. Student response was expected to be limited, so instructors were asked to offer extra credit to incentivize higher response rates.

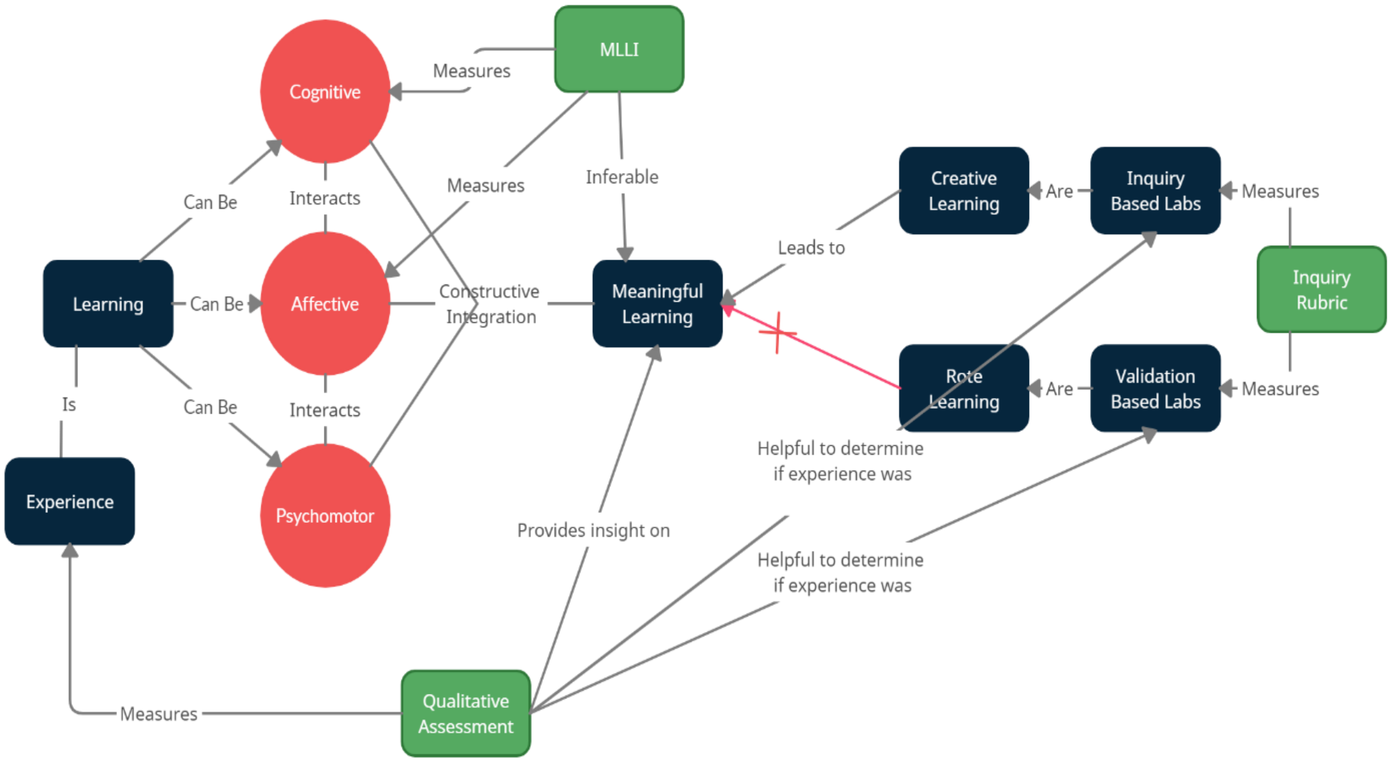
Theoretical Framework

This study employed Novak's Human Constructivism theory (1993). According to Novak, meaningful learning occurs from meaningful experiences. For meaningful learning to occur, the student must have associated thinking (cognitive domain), feeling (affective domain), and acting (psychomotor domain). Each of these domains interacts with one another, buildings toward meaningful learning.

Figure 1 shows a concept map used to devise this study. The concept map is a way to draw inferences between different components to help build understanding or map out study plans also developed by Novak (1990). In this case, each green box relates to one of the three quantitative or qualitative assessments performed in the study. Each of the blue boxes is a different important component related to the study and integration into Human Constructivism. The red circles relate to the three different learning domains.

Figure 1

Concept Map Dictating the Relationship Between Study Components and Novak's Theory of Human Constructivism



The concept map shows that the qualitative assessment was used to evaluate students' experience during ERT. In addition, qualitative questions provided insight on whether meaningful learning occurred and student perception of inquiry during their experience with the online laboratory components of chemistry classes. The Inquiry Rubric Tool (IRT), created for this study, assisted in that determination. Novak (1998) pointed out that rote and meaningful learning is on opposite ends of a spectrum, yet not wholly exclusive. Rote learning can contribute to meaningful learning through practice, rehearsal, and thoughtful repletion. Without this extra work, rote learning does not lead to meaningful learning.

Inquiry-based assignments align more with reactive learning, while validation experimentation is closer to rote learning. Finally, MLLI assessed students' cognitive and affective domains during their ERT experience at El Camino College. This information was inferential to whether meaningful learning occurred or not. The psychomotor domain was not assessed actively, though the questions involving MLLI and the qualitative section elicited psychomotor information.

Significance of Research

Understanding the experience of El Camino College students during ERT adds to the knowledge gathered during the pandemic and helps develop further curricula. Student experiences give insight into the preparation of ERT teaching pedagogy if schools are placed in such a situation again. Kelley (2021a) stated that the pedagogy development based on knowledge obtained during ERT online courses might be helpful if similar problems arise or if funding is limited. Instructors will have a prebuilt alternative if their lab classes are cut. In addition, this work gives instructors insight into what to expect of their students as the school moves back to in-person instruction.

In recent articles, many chemistry instructors stated that their experience during COVID-19 led them to evaluate their current pedagogical work (George-Williams et al., 2020; Kelley, 2021a; Schweiker & Levonis, 2020; Wilson, 2020). Activities developed online that lead to meaningful learning may be incorporated into the current curriculum. Study results from this work may help pilot changes in any materials used in hybrid learning. In addition, this work provides a unique perspective as instructors move back to face-to-face teaching to develop more inquiry-based experiments for their classes.

The next chapter delves into a literature review of all essential concepts, including - this study’s framework, theorems on chemistry instruction, validation, inquiry-based teaching styles, and instructors’ alternative learning methods during ERT. Finally, the Meaningful

Learning in the Laboratory Instrument will be expounded upon as one of the primary tools for this work.

Chapter 2: Review of Relevant Literature

This literature review aims to explore the concepts that led to this research project, important articles relevant to the research questions, the effect of COVID-19 on student learning, and a potential tool to measure learning. This review will discuss Novak's Theory of Meaningful Learning and its use in chemical education literature. In particular, the use of Novak's Human Constructivism will be covered in terms of laboratory experiences.

Novak's Theory of Meaningful Learning will be used as a guiding framework for this research. This theory has been essential for understanding the importance of laboratory experimentation in meaningful chemistry education (Bretz, 2001). Several articles have argued that laboratory experiments may not be helpful in the current curriculum. These will also be explored, followed by probing the difference between verification and inquiry-style experiments. During the pandemic, El Camino College was put on an ERT hold in which instructors decided how to proceed with laboratory experimentation. Understanding the different types of experiments in the literature is essential for building a foundation.

Research articles detailing the experiences of instructors and students during the COVID-19 pandemic were essential to understanding the importance of the research project. This preliminary research prioritized determining an instrument for measuring their experiences. The MLLI became the chosen tool. Literature was reviewed on its prior use and how best to proceed with its implementation, which will be discussed here. Full implementation and statistical activity will be discussed in Chapter 3.

Novak's Theory of Meaningful Learning

The work by Joseph D. Novak, whose framework became the basis of this research, was built on David Ausubel's theories of assimilation and meaningful learning (Ausubel, 1963, 1968). Ausubel posited that the ability to reason about a specific topic depends on a person's conceptual framework in that domain. Therefore, meaningful learning occurs when students process new information and connect it to their existing knowledge. More recent formulations would articulate the process as assimilating newly acquired information into existing structures to form updated conceptual systems. Sometimes the procedure is rapid and sometimes gradual.

Ausubel (1963, 1968) stated that for learning to take place, the following must be true:

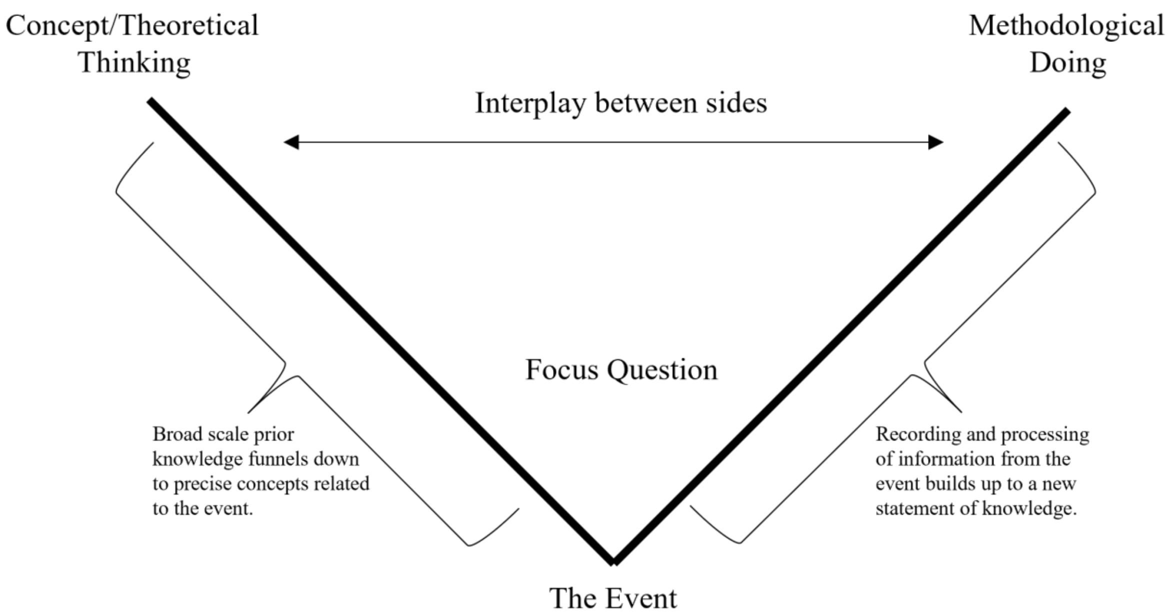
- the student must have prior, relatable knowledge about the topic;
- the new material must be meaningful on its own merits, containing important concepts relatable to the prior knowledge;
- a student must choose to incorporate this new knowledge into their learning set.

Bretz (2001) stated that working in these three domains is incredibly difficult for a chemistry instructor. There is only one of the three that an instructor can develop a curriculum based on—organizing material to connect to a student's prior knowledge and be attractive enough for the student to wish to incorporate it. A student's prior knowledge is not governable. Their choice to include that data is also not up to the instructor, though instructors must attempt to sway this decision. This is critical to developing an informative and engaging curriculum for students to partake in meaningful learning. To increase meaningful learning, further theory development was required.

Novak's Theory of Education, often called Human Constructivism (1993), is built on enabling students. Novak (1993) indicated that instructors must create classwork that allows students to construct data based on previous experience and be interesting enough for them to want to incorporate it. Novak's research started with exploring problem-solving abilities developed in a botany course (Novak, 1957). Novak (1993) stated that concepts or extensions are assimilated into ones knowledge base, but it is essential to remember that humans are part of a community. Extending Ausubel's theory, Novak posited that concepts understood by a community evolve as the community grows and changes. He argued that there is a need for both psychologists and epistemologists to “focus on the process of meaning-making that involves the acquisition or modification of concepts and concept relationships” (Novak, 1993, p. 184). In other words, teachers can better instruct their students by understanding the norms of assimilation.

Novak (1993) referenced the Vee heuristic described by Gowin (1981). Figure 2 shows an example of the Vee heuristic, a diagram with theories leading to an event and the discoveries therein. In a Vee heuristic, the left leg dictates theories or important concept information, the point acting as the central experience, and the right leg dictates analysis or evaluation. Human Constructivism is experiential by nature, so this format aligned well with Novak's theories.

Figure 2
Gowin Vee Describing the Development of New Knowledge by Experience



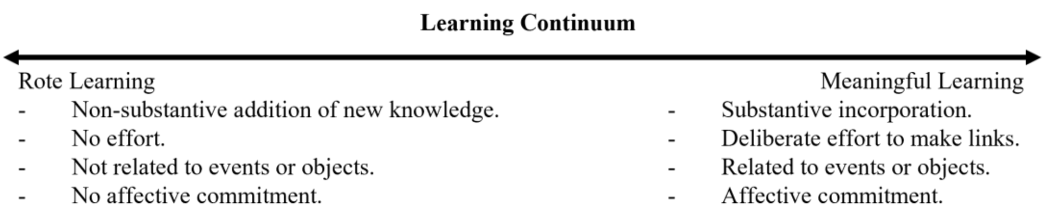
The general form for the Vee is shown in Figure 2 as it relates to Human Constructivism. The left side of the Vee demonstrates a gradual breakdown of the epistemological elements involved in learning. Not every portion of the epistemological aspects must be used during the development of a Vee. The event is the central component at the tip of the Vee. Novak (1993) determined that individuals construct their knowledge based on previous knowledge and experience. This acts as a pivot point between concept and doing. Once the event has occurred, further evaluation is done through records, transforming the knowledge into useful components, then constructing knowledge and value claims. Human Constructivism is about building on concepts, which Novak states is “defined as perceived regularities in events or objects designated by a label” (Novak, 1993, p. 171). Anything that is commonly experienced, we denote with its own vocabulary.

Meaningful learning and rote learning are often seen as directly at odds with one another (Novak, 1998). Rote learning describes when a person learns through memorization, with no relation to prior experiences necessary. Novak notes that rote learning has its place, but the real benefit of rote learning is when meaning can be moved from what is memorized (Novak, 1998). Similarly, Battino (1992) indicates that rote learning can be helpful in chemistry by acting as a platform to build meaningful learning.

Novak (1998) noted that rote learning is often encouraged due to its ease. Chemistry is no different. Herron (1996) stated that students in chemistry usually prefer rote learning over meaningful learning because it requires less cognitive effort. Figure 3 shows the continuum between rote and meaningful learning. Most school learning happens within the area of rote learning. To move to creative processing, meaningful learning must occur.

Figure 3

Meaningful Learning and Rote Learning Continuum



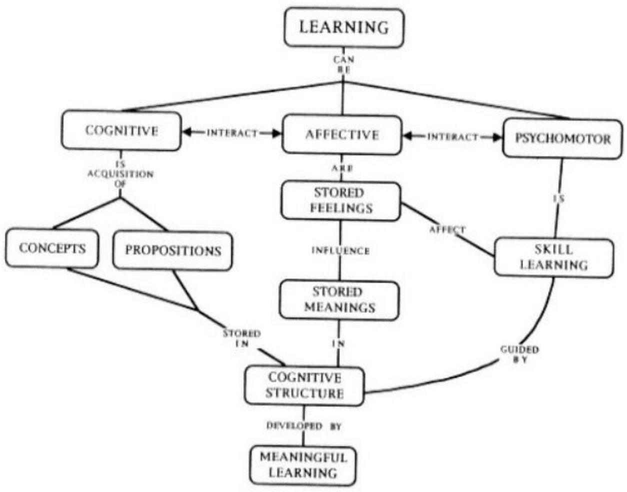
Note. Adapted from *Learning, creating, and using knowledge: Concept maps as facilitative tools in schools and corporations* (p. 30) by J. D. Novak, 1998, Lawrence Erlbaum Associates. Copyright 1998 by Lawrence Erylbaum Associates.

Novak (1993, 1998) pushed instructors to think about how they can relate their materials to their students to build stronger concept links and make what the student is learning non-arbitrary. Novak compares rote learning and meaningful learning to the difference between an artist and a technician. A technician can play musical notes they have memorized, but an artist understands the importance behind the music. There must be an effort placed into developing the latter.

At its core, Human Constructivism states that for meaningful learning to happen, there must be an interaction between thinking, feeling, and acting. The constructive integration of these items leads to "human empowerment for commitment and responsibility" (Novak, 1998, p. 13). Novak noted (1998) that successful education is a complicated overlap between three different domains that can lead to meaningful learning – cognitive, affective, and psychomotor. Concept maps, a tool for visually linking various components, is one of the introductions for which Novak is well known (Novak, 1990). The concept map for the three domains is shown as Figure 4.

Figure 4

Concept Map Explaining the Development of Meaningful Learning



Note. Adapted from *Learning, creating, and using knowledge: Concept maps as facilitative tools in schools and corporations* (p. 26), by J. D. Novak, 1998, Lawrence Erlbaum Associates. Copyright 1998 by Lawrence Erylbaum Associates.

Bretz (2001) summarized Novak's definition for each of the different domains. Bretz (2001) described the cognitive component as concepts and reasoning skills, the affective domain as attitudes and motivation, and the psychomotor as dexterity and precision. Each of the domains should overlap, as shown in the concept map in Figure 4. Each of the domains is important and interacts with one another. Novak (1998) stated that meaningful learning builds on refined cognitive structure. Cognitive structure was defined as previous experiences and cognitive understanding. A significant interaction between the cognitive, affective, and psychomotor components contributes to developing this cognitive structure and changing it, which finally leads to meaningful learning.

For example, a student in the laboratory environment is often engaged in all three components. The psychomotor and cognitive components are often prioritized (Bretz et al., 2013), yet the affective domain is still vitally important. How students feel about their learning will affect whether they find it worthwhile to store the feelings, which affects accumulated meanings. A student in a lab may learn through physically experimenting and capturing data on their own, learning a new skill such as titration. This may allow them to connect the cognitive side through propositions—the grouping of multiple concepts together. A titration can enable a student to get hands-on experience, building a new skill while taking concepts such as molarity and stoichiometry to combine as propositions and finally change the cognitive structure.

Bretz (2001) stated that these domains are critical in learning chemistry. Furthermore, she included that failure to address all three domains and their interaction in curriculum development will prevent students from obtaining meaningful learning. While students may view the laboratory as the prevue of the psychomotor domain (DeKorver et al., 2015), a well-rounded laboratory experience in all three domains is vital.

Epistemic Frame

A wide variety of learning frameworks can describe student laboratory experiences. Kolb's Experiential Learning Theory (Towns, 2001), Transformative Learning (Wink, 2001), Project-Based Learning (Wenzel, 2007; Yang et al., 2021), and Communities of Practice (Benatan et al., 2009; Xie et al., 2021) have been used in chemical education literature to frame learning in the laboratory. There is a framework specifically designed for laboratory learning (Seery et al., 2019). Even Piaget's theories have been used by chemists (Bunce, 2001; Herron, 1975) to describe how students learn chemistry and the importance of social interaction in building a construct.

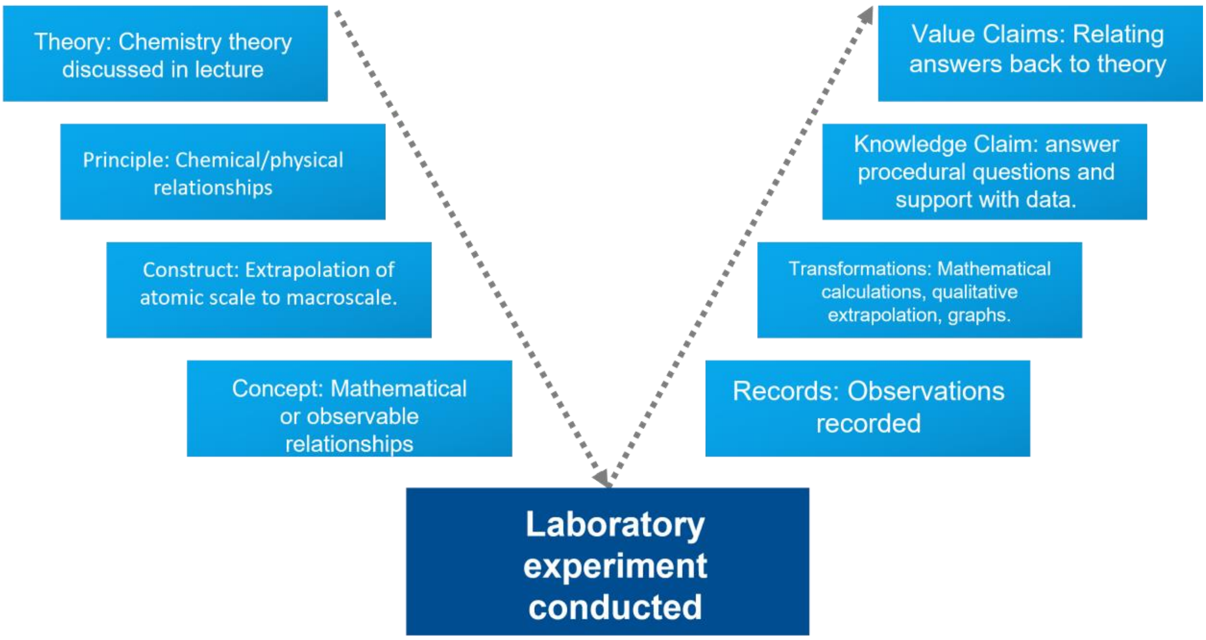
Novak's theory has received attention in chemical education (Ebenezer, 1992; Fazal et al., 2020; Fergus et al., 2021; Fountain & McGuire, 1994; Gabel, 1999; Galloway et al., 2018; Popova & Bretz, 2018; Schaller et al., 2015; Smith et al., 2018;). Articles sometimes revolve around moving from rote to meaningful learning (Afzal et al., 1990; Cardellini, 2004; Grove & Bretz, 2012; Lipton, 2020). Novak's Human Constructivism often provides a lens to view chemistry laboratory learning (An & Holme, 2021; Burrows et al., 2021; Dekorver & Towns, 2015; Flaherty et al., 2017; Mason, 2004; Miller & Lang, 2016; Santos-Díaz et al., 2019; Zhang et al., 2021). Online learning based on laboratory experiments, ERT laboratory classes, and hybrid chemistry classes have also used Novak's theory as a basis (Baldock et al., 2021; Dickson-Karn, 2020; Jones et al., 2021; Pölloth et al., 2020; Williams et al., 2021).

While prolific in chemical education literature, the author chose Novak's framework due to personal experience. The author feels the chemistry laboratory is a place for holistic learning. Students get a chance to do things with their hands (psychomotor) that they may never be able to experience if they did not take a chemistry course. Experiments are often selected to build student interest and engagement (affective) through brilliant color change, bright light emission, and similar results. Finally, laboratories are meant to build on complex chemical theories that may not make sense without actually experiencing the grounding of the theory (cognitive).

Figure 5 shows a Gowin's Vee diagram depicting the author's framework for conducting a typical lab. The author perceives the goal of laboratories as a link between theories and practice, as well as to engage students in meaningful learning. The left leg of the Vee involves building up to the laboratory experiment. The experience, the laboratory experiment, occurs at the Vee's tip. On the right leg of the Vee, data extrapolation and linkage to theory happen.

Figure 5

Gowin's Vee Describing a Typical Chemistry Laboratory Experience



As an example, the measurement of sulfate (SO_4^{2-}) by the precipitation with barium (Ba^{2+}) through the production of barium sulfate ($BaSO_4$) will be described. During lecture, instructors first describe a theory. In this case, the Law of Conservation of Mass acts as a theory – matter is neither created nor destroyed. Instructors then describe guiding principles making up that theory. In this case, a chemical reaction is beneficial. For this example, the precipitation of barium sulfate is shown as:

$$BaCl_2\ (aq) + Na_2SO_4\ (aq) \rightarrow BaSO_4(s) + 2\ NaCl\ (aq) \quad (1)$$

Both solutions on the left-hand side are soluble, whereas barium sulfate is precipitated out on the right. Atoms do not change during a chemical reaction; they simply change their bonds. This reaction states 'one aqueous barium chloride formula unit reacts with one aqueous sodium sulfate formula unit to produce one solid barium sulfate formula unit and two aqueous sodium chloride formula units.' The number of atoms and their identity are the same on the left as the right, yet their connectivity has changed.

Extrapolation from the atomic scale to the macroscale then happens. Students cannot see individual atoms making bonds but will see a clear, colorless solution (left side of the equation) becoming cloudy due to the solid formation on the right. Mathematics then allows for the conceptualization of these values through stoichiometry, molar mass, and other calculations.

Up to this point, all the instruction has been done as a lead-up to the laboratory experiment. In the lab itself, students can take measurements, make observations and perform actual reactions. During the barium sulfate experiment, students make mass measurements and observations. Adding barium chloride to sodium sulfate will create a white-colored precipitate that students can visualize. Records are taken in terms of initial masses and final masses. Calculations can then be performed. Lab procedures often come with a set of questions to answer, which are meant to guide the development of theories covered in the lecture. In this case, a chemical reaction can be used to evaluate the Law of Conservation of Mass—the masses and atoms going into the reaction equal the same coming out.

The goal of teaching laboratories is to encourage meaningful learning in students. Students can become actively engaged with the material instead of acting as passive learners. Rote memorization takes a back seat to the application of theory, where students generate their own results. While each lab instructor handles their classroom differently, the author of this work finds each of the three domains described by Novak (1993) to be fundamental in a fulfilling laboratory experience. Using equipment, students learn to make precise measurements via a hands-on experience (psychomotor). The author often walks around during lab, asking students to explain what they are doing and why (cognitive). Cognitive aspects are also engaged during post-laboratory write-ups where students attempt to link what they are learning to theory in lecture. In addition, the author often asks students how they feel about the experiment and their results (affective). This later is incredibly important to the author as frustrated students often miss critical findings.

Before beginning this dissertation, the author did not know about Novak's Theory of Human Constructivism. While searching for helpful measurement tools to determine the experience students had while performing laboratory experiments in ERT, the MLLI devised by Galloway and Bretz (2015a) stood out as a helpful instrument. The theory the MLLI uses is based on Novak's work and led to the choice of framework for this work. While an older approach, and one present amongst several others, Novak's theory resonated with the author's previous experience.

The MLLI survey will be covered later in this literature review. As previously stated, the author was unaware of Novak's work and its prevalence in the field of chemistry education. Another factor that the author did not fully understand is the presence of an ongoing dialogue on whether laboratory experiments are worthwhile. This was completely unexpected. To broach this topic, a brief history of laboratory experiments and both sides of the argument will be covered.

Laboratories in Chemistry

Hands-on teaching experiences can be traced back to Justus von Liebig, often considered the father of organic chemistry (Pickering, 1993). Students under his tutelage were expected to work in the lab, though it could better be equated to a modern graduate research lab. Charles Eliot and Storer (1869) wrote one of the first inorganic-based chemistry laboratory manuals containing 260 experiments. Experimentation was considered an essential part of chemistry until the 1920s and 1930s (Pickering, 1993). At this point, demonstrations during lectures were considered more compelling, where the instructor collected data and gave it to the students for analysis. Pickering (1993) indicated that the use of teaching laboratory exercises “won out,” possibly for no more reason other than that the instructors enjoyed them and wanted students to share in that joy. Pickering (1993) further noted that laboratory assignments were easier to prepare and could be pushed to the wayside if faculty got busy.

During the 1950s and 1960s, teaching laboratory experiences saw an expansion in chemistry. Many students were going to college during this time, and the increase in baby boomers entering the classroom made for larger laboratory classes (Pickering, 1993). Additionally, the race to space inspired American students into scientific careers (Hunnings & Hunnings, 1981; Kieffer, 1980). For Americans to compete, funds were poured into the sciences through the National Science Foundation. This influx in funding allowed instructors to attend conferences where the goals were to improve the content of laboratory experiments and how they were conducted (Orna, 2015). Hands-on laboratory experiences increased, including programs like Chemical Education Materials Study (CHEMS) in 1962, where high school students could experience chemistry firsthand (Kieffer, 1980; Orna, 2015). There was a significant paradigm shift away from cookbook-based experiments to those that engage students creatively (Eubanks, 2015).

Laboratories continue to be a component of chemistry at all levels. Pienta (2010) wrote in an editorial regarding the threat to undergraduate laboratories that the *Journal of Chemical Education* has over 10,000 citations regarding “laboratory experiments.” Yet, a debate has been ongoing for decades: are chemistry teaching labs worthwhile? In the following two sections, both arguments are reviewed.

Advocation for Laboratory Exercises

The laboratory experience is a long-cemented part of the science-based curriculum. W. G. Bowers, in a 1924 article, is often cited as one of the earliest advocates for the importance of laboratories in chemistry. Unfortunately, his sample size was minimal (one set of students). Bretz (2019) remarked that the evidence would never be accepted using the rigor of today's Journal of Chemical Education. Yet, if one were to ask a chemistry instructor, they will generally defend the importance of the lab. Eubanks (2015) indicated that authors in the 20^{th} century no longer need to defend their laboratory instruction and simply include it, though how it is taught is still essential.

A review of the literature shows that many authors still defend laboratories as a necessary component in the sciences (Clough, 2002; Hodson, 1988, 2001; Hofstein & Lunetta, 2003; Johnstone & Al-Shuaili, 2001; Lunetta et al., 2007; Magin, 1984; Tobin & Gallagher, 1987). Laboratory experiments are denoted as a place to develop inquiry, investigations, and problem-solving (Hodson, 2001; Hofstein & Lunetta, 1982; Tamir & Lunetta, 1981) or ways to build an understanding of scientific work (Hofstein & Lunetta, 2003). Tobin (1990) stated that the chemistry laboratory is a place for students to build an experience and construct an understanding from it.

Anderson (1976) wrote that there are four different goals for laboratory work, primarily revolving around increasing student intelligence and understanding as well as science inquiry skills. Laboratory goals also included increasing appreciation for the sciences, scientists' role, and the orderliness of scientific theories and models. Similarly, Shulman and Tamir (1973) stated that the goals of the scientific lab include arousing interest in sciences, building creative thinking and problem-solving skills, developing scientific thinking, building intellectual ability, and developing hands-on practical skills.

Chemistry laboratories have also been shown to have other benefits. Cooperative learning is a common experience during labs. These collaborative learning experiences benefit students and allow them to take charge of their learning (Cooper & Sandi-Urena, 2013; Sandi-Urena et al., 2011). Pickering (1987) stated that laboratories may help understand the scientific method, improve understanding of complex theory, and develop confidence with hands-on techniques. Hodson (1996) remarked that students could be motivated and engaged in practical work if experiments are interesting and exciting.

The American Chemical Society feels that a hands-on experience is vital to a student's learning. In the Undergraduate Professional Education in Chemistry—ACS Guidelines and Evaluation Procedures for Bachelor's Degree Programs (2015), ACS requires 400 hours of laboratory experience beyond introductory chemistry to be considered for certification. Further guidelines published as Excellent Undergraduate Chemistry Programs (2016) stated that a genuinely student-centered curriculum will have hands-on laboratory experiments to promote “observation of phenomena, critical thinking, and interpretation of data” (p. 1).

Argument Against Laboratories

Starting in the late 1970s, some educators began to ask whether laboratory exercises were worth the time, effort, and cost in the education of students. For example, Bates (1978) indicated that the importance of laboratory exercises might not be as self-evident as educators may think. Pickering (1982) directly postulated whether labs are worthwhile in an article titled “Are Lab Courses a Waste of Time?” In the article, Pickering (1982) pointed out several issues with laboratories, including:

- many labs do not illustrate lecture courses as it is too difficult to summarize essential items in a single afternoon exercise;

- labs do not teach what Pickering calls 'finger skills.' Most techniques learned in a lab are either outdated or won't be directly usable;
- labs are not following the Socratic method in which they should be done.

Other authors have also criticized the use of labs. Wills (1974) noted that half of the students in a biochemistry practical course showed little enthusiasm. In the same study, students gained little theoretical knowledge through practical exercise. Hawkes (2004) argued similarly, stating that the expenditure of money and the dislike students hold for the lab are not worth the time lost. Hodson (1991) indicated that lab work, as currently taught in many school systems, was often unproductive with no clear goals. Students are often not given a chance to develop cognitive skills during laboratory sessions (Lunetta & Tamir, 1979). Many laboratory experiments are often considered dull and useless due to a cookbook approach where students simply follow a set of given instructions with expected results (Roth, 1994). The National Science Board (1986) stated that laboratory instruction has degenerated to the point of being "uninspired, tedious, and dull." It is little wonder there is a call for more research on the helpfulness of the laboratory.

Hofstein and Lunetta (1982) published an oft-cited article calling for further research on the role of laboratory experiments in the sciences. The authors stated that while laboratory exercises have long been a central component of the sciences, there has been little review on their usefulness. Furthermore, they added that there is too little data to support or deny the importance of these labs (Hofstein & Lunetta, 1982). Several shortcomings in laboratory exercises were pointed out, including:

- small sample sizes;
- insufficient control over the procedures;
- poor assessments that do not match with goals;
- inadequate reporting of assessment and instructional practices.

Interestingly, Hofstein and Lunetta (2003) returned to the same subject twenty years later. Still, they reported no significant data supporting the necessity of laboratory exercises. In their review, the authors stated that there had been progress. Some variables have been identified that may aid in meaningful learning, but there is still a data gap.

The gap in illustrative data posed by Hofstein and Luneta (1982, 2003) still exists. Recently, Bretz (2019) made a similar call to action. Data collection for understanding the importance of lab and a shift in pedagogy are vital. Bretz (2019) stated that chemists must expect the same rigor when making any statement as empirical scientists. If chemists say that the lab is essential, they must prove it. In addition, Bretz (2019) noted that powerful pedagogical tools like MORE (Model-Observe-Reflect-Explain) developed by Tien et al., (2007) or Argument-Driven Inquiry (Walker et al., 2011) are not seeing active use in the classroom.

Hofstein and Lunetta (2003) pointed out a discrepancy between what is recommended and what is taught in the classroom. They stated the following items appear to inhibit learning in the laboratory:

- the use of cookbook-style instruction that does not engage students;
- assessment of practical knowledge and abilities is rare;
- instructors and administrators do not keep up to date on suggested pedagogical methods;
- lack of inquiry-based activities.

The argument of whether labs are essential or not still needs data to support either side. As Hofstein and Lunetta (2003) indicated, there is a distinct lack of inquiry experimentation. This is also common at El Camino College. Most of the experiments performed in the laboratory bear expected results and have the student follow a procedure to achieve this outcome. Inquiry is challenging to define, though. The following section explains inquiry-based laboratory experimentation compared to validation exercises.

Inquiry-Based Learning

Inquiry-based learning engages students in the scientific process. This learning style is grounded in applying the same thinking, techniques, and activities that scientists do in research (National Research Council [NRC], 2000). Inquiry-based learning relates back to the Socratic method of having students engage in dialogue and question what they see (Friesen & Scott, 2013). Inquiry started to enter the spotlight as John Dewey addressed the American Association for the Advancement of Science, stating that science isn't simply a body of knowledge to be learned, but there is a method as well (Dewey, 1910).

Following Dewey, Joseph Schwab was another influential member of increasing inquiry in the classroom. Schwab indicated that science education and science itself should constantly be revised as new findings are presented (NRC, 2000). This means that students should be learning the sciences as researchers work—one in which there are unknowns, where they build hypotheses and test their findings.

Schwab pushed for the importance of the laboratory in developing education and notes that it is a point easily converted to inquiry (Schwab, 1960).   Schwab stated this is done by having the laboratory lead rather than lag the point where the classroom is. That is, allow students a chance to attempt materials in a laboratory through exploration before they have an opportunity to learn the theory behind materials in lecture.

As discussed above, the laboratory continues to be a component of chemical education. Yet, inquiry-based learning has taken several branches since Schwab's publications. The following section describes the connection in the literature between inquiry and chemistry.

Verification vs. Inquiry in Chemistry

Verification and inquiry often stand at opposite ends of a spectrum, with verification experiments directed by the instructor and inquiry-based assignments giving students more freedom. Verification experimentation is common in teaching laboratories (Basey et al., 2000; Deters, 2005; Hodson, 1991; Millar & Abrahams, 2009). Verification labs are laboratory experiments that provide evidence for a specific concept (Abraham, 2011). They have an expected outcome and often follow the cookbook instructional style Hofstein and Lunetta (2003) disdained.

Verification experiments can be defined as taking three steps—Inform, Verify, and Practice (Renner, 1982). For example, an instructor will inform a student that they are titrating hydrochloric acid with sodium hydroxide. They are to look for a pink color when completed. The student performs the experiment, comes up with an answer already determined by the instructor, then repeats the experiment. The laboratory component of the Inform-Verify-Practice happens during the Verify portion.

Inquiry-based instruction is often challenging to describe regarding chemistry as it is a complex idea that is both a mode and topic of instruction (Flick, 1995). At its core, doubt is seeded in the classroom (Schwab, 1962). Students are not directly given answers. Students should be asked to question every component of the instruction. Martin-Hansen (2002) noted that when students work at building hypotheses, collecting data, and analyzing the data, they effectively participate in inquiry. This is directly at odds with many of the cookbook-style laboratory assignments instructors use. Flick (1995) synthesized literature articles in a review and denoted the following propositions to describe inquiry-based learning:

- a practice where the teacher enables a student to use prior knowledge to generate new information, approaches, and solutions;

- open-ended problems, with the student focusing on the goal, not a particular 'correct' answer;
- reflection on facts, concepts, and models. Interesting problems by themselves are not enough;
- effectiveness of students is mainly hindered by lack of knowledge, low status, inadequate materials, and teacher reluctance to relinquish control;
- addition of structured inquiry can support students who are behind or if the materials are complex;
- instructors must teach to all students, not just the most abled. All students should develop critical thinking skills;
- students must be trained to interact with a group.

Similar to verification style laboratories, Renner (1982) also defined a three-step process involved in inquiry-based instruction. These three steps were explore, invent a concept, and apply it. This process followed much more closely with the scientific method of establishing a hypothesis, testing, and confirmation that chemistry teaches. In the inquiry model given by Renner (1982), experimentation generally happens during the explore phase, though it may occur at any stage. This matches with Schwab’s (1960) ideas on exploring a topic in a laboratory setting first. An example of this type of experiment would be a typical second-year organic synthesis experiment. Instructors give students a compound they must synthesize from starting materials and little other information. The student must develop a complete synthesis setup based on literature and prior experience. They perform the experiment, then confirm the identity of their chemical.

The difference between verification laboratories and inquiry can be considered a continuum (Martin-Hassen, 2002; Eubanks, 2015). As a student is given more control and the teacher contributes less, the laboratory exercise goes from verification to inquiry. Figure

6 below was initially published by the NRC (2000). In a pure inquiry-based experience, the student poses the question, determines the experiment and how it is presented, reviews the literature, and postulates a logical argument. In a complete verification experiment, the instructor provides the questions, the student is given data and provided with the evidence, and finally is told how to present the data.

Figure 6

National Research Council's Description of Student-Based Direction vs. Instructor-Based Direction

Essential Feature	Variations			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies questions provided by teacher, material, or other source	Learner engages in questions provided by teacher, materials, or other sources
2. Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpened communication	Learner given steps and procedures for communication
More	Amount of learner self-direction			Less
Less	Amount of direction from teacher or material			More

Note: Adapted from *Inquiry and the National Science Education Standards* (p. 29), by the National Research Council, 2000. Copyright 2000 by National Academy of Sciences.

Inquiry has had a wide variety of modifiers, such as traditional inquiry and guided inquiry, with definitions in the literature that may be out of sync with one another (Colburn, 2000; Farrel et al., 1999). Buck et al. (2008) developed a rubric to characterize and define inquiry. Their rubric was built on previous work by Schwab (1962), Herron (1971), Chinn and Malhotra (2002), and Brown et al. (2006). Schwab's (1962) work laid the foundation for the rubric, with four different levels but only three separate considerations (Problem, Ways/Means, and Answers). The new rubric is very similar to the one Fay et al. (2007) developed, except for an additional level of inquiry. The goal of the rubric was to be able to quickly assess laboratory exercises and identify them as a specific type of inquiry.

The rubric for the characterization of inquiry is shown as Figure 7. Six different components made up the rubric compared to Schwab's (1962) original three. All components are in relationship to student freedom. Concerning terminology, the problem/question component does not reference the difficulty of the question but whether the student determines the goal or the instructor. Theory and Background referred to whether students had to do independent research to investigate the basis for the experiment or if it was provided. Result Analysis is related to students being informed on how to analyze the data or having the freedom to look deeper to determine how to use the results. Results Communication was a component pertaining to how the materials were presented—were students able to choose how they disseminated the information, or was it dictated to them. Conclusions mean whether the lab procedure detailed what the students should report or if students could provide the findings openly. This also reflects whether or not there was a foregone conclusion at the onset of the experiment. Figure 7 shows whether the item was provided by the instructor (P) or if the student had to determine it (NP).

Figure 7

A Rubric Developed to Characterize Laboratory Experiences Based on Levels of Inquiry

Item	Level 0 (Confirmation)	Level ½ (Structured Inquiry)	Level 1 (Guided Inquiry)	Level 2 (Open Inquiry)	Level 3 (Authentic Inquiry)
Problem/Question	P	P	P	P	NP
Theory /Background	P	P	P	P	NP
Procedures/Design	P	P	P	NP	NP
Results Analysis	P	P	NP	NP	NP
Results Communication	P	NP	NP	NP	NP
Conclusions	P	NP	NP	NP	NP

Note. Adapted from "Characterizing the level of inquiry in the undergraduate laboratory" by L. B. Buck, and S. L. Bretz, 2008, *Journal of College Science Teaching*, *38*(1), p. 54. Copyright 2008 by National Science Teaching Association.

The rubric includes four different classifications of inquiry, following a similar spectrum shown in the NRC (2000) continuum. Level 0 is classified as Confirmation or using terms from earlier in this literature review, Validation. In this level of inquiry, the instructor and materials guide all learning throughout the experiment. The student has little to no freedom for inquiry. Examples include cookbook-style investigations with specific procedures, familiarization with equipment, and watching another perform an experiment and observing phenomena, with the instructor detailing what is observed. Level ½, Structured Inquiry, is where students may begin to devise how to communicate their findings and do not know the answers to what they are doing when they enter the experiment. This type of experiment can include a step-by-step procedure containing unknowns, and students must identify their unknown.

Levels 1, 2, and 3 begin to break into the inquiry model deeply. In a Guided Inquiry setting, procedures are provided to students, but they must decide how to analyze the data they collect. Determining how to characterize a product from an organic synthesis would fall under this type of experimentation. Students may not necessarily be told how to characterize their product and must decide how to handle the process. Level 2 was the Open Inquiry model, in which students are only provided with a question and some theory but must develop a procedure independently. This often includes literature research.

An example of this is a culmination organic experiment. Students are provided the starting and ending materials but must determine how to achieve this, characterize it, and report it. The most student-directed learning environment is portrayed in Level 3, Authentic Inquiry. This type of research may include legitimate undergraduate research where students must review the literature to determine a problem and what they wish to investigate.

Buck et al. (2008) evaluated 386 different laboratory activities during the pilot study of their rubric. They encompassed geology, chemistry, physics, physical science, meteorology, and astronomy. Using the rubric, the authors noted that 191 out of 229 reviewed experiments in chemistry were classified as Level ½. Twelve experiments were classified as Level 0, 21 as Level 1, and five as Level 2. No experiments were classified as Level 3. Buck et al. (2008) noted that their rubric provides a way for faculty to monitor and improve the degree of inquiry present in their classes.

The National Science Education Standards (National Research Council, 1996) called for inquiry-based work to be foundational in science education, especially in labs. In 2013, the NSES was replaced by the Next Generation Science Standards (NGSS), which emphasized the need for inquiry-based laboratory action (Next Generation Science Standards [NGSS], 2013). Reviews of the literature show that inquiry-based experimentation results in better student outcomes, higher levels of learning, and better student attitude (Abraham, 2011; Blanchard et al., 2010; Cacciatore & Sevian, 2009; Deters, 2005; Hall & McCurdy, 1990; Leonward, 1983).

Before the COVID-19 pandemic, most of the laboratory experiments at El Camino college would likely have fallen under Levels 0 and ½ for general and organic chemistry. In addition, all experiments were conducted in person—there were no online-only courses.

Remote and online laboratory experiments have received time in the literature, and debate continues on whether they can have the same educational venue. Once the college mandated ERT, laboratory teaching style was left to the individual instructor. The following sections will focus on remote laboratory experimentation in pre-COVID-19 learning environments.

Remote and Online Laboratory Experimentation

As technology progressed, its inclusion in the chemistry field also grew. The use of hybrid and virtual laboratory experiments has received attention in the literature, though similar to the debate on the importance of labs, their implementation is still in discourse (Ali & Ullah, 2020; Boschmann, 2003; Corter et al., 2011; Erdmann et al., 2021; Irby et al., 2018; Pyatt & Sims, 2012; Sickler et al., 2004; Winkelmann et al., 2017;). Burchett et al. (2016) indicated that virtual labs could help alleviate laboratory capacity issues. Pyatt and Sims (2012) found that students preferred inquiry-based virtual laboratory experiments and experienced more positive attitudes than their in-person counterparts. In some cases, remote labs have produced similar or better results than in-person experimentation (Cobb et al., 2009; Irby et al., 2018; Tatli & Ayas, 2013).

Not all literature has shown promising results. The American Chemical Society Committee on Professional Training states that virtual labs are helpful for supplementation but not for replacing hands-on activities (ACS Guidelines, 2015). Online chemistry courses also have higher drop-out rates (Brewer et al., 2013; Boschmann, 2003; Carr, 2000; Howell et al., 2004). The cost of a subscription or outright purchase of software may be expensive (Limniou et al., 2008). Often, virtual laboratories are static environments where values do not change based on student experience, nor do they offer guidance to students on how to use the software/complete the experiment (Ali & Ullah, 2020). Students also have reported a preference for hands-on activities even when learning outcomes were higher for virtual and simulated activities (Corter et al., 2007, 2011)

In 2000, Mary Jane Patterson published an article in the Journal of Chemical Education giving guidelines on creating Internet-based chemistry courses. A section was set aside for the laboratory. In this section, Patterson (2000) stated that several options exist, including hybridizing a course where labs are done in person, performing virtual labs, using purchased lab kits, or performing the class without a specific lab. Since hybridization was not an option during ERT at El Camino College, only virtual labs, virtual experiments, and home chemistry will be discussed.

Secondhand Experimentation and Data Computation

When El Camino College was forced into ERT, instructors had the freedom and burden of choosing how to proceed. An informal faculty survey showed that most instructors decided to take current experiments and rewrite them to match an online format. Techniques included creating videos or finding videos on Youtube for students to watch, creating data sets for experiments, or giving the students observations.

This type of work falls directly aligns with the confirmation-style laboratories, as it offers little opportunity for student exploration. This was not uncommon during the pandemic (Woelk & Whitefield, 2020). These confirmation-oriented laboratories also occurred before the pandemic (Agustian & Seery, 2017; Elliot & Kukla, 2007; Stieff et al., 2018). Some used video recordings and picture explanations for pre-laboratory experiments (Agustian & Seery, 2017; Chittleborough et al., 2007; Stieff et al., 2018). Excel-based simulations have been used to create large data groups for student computation (Perri, 2020). Tools like Chem-Wiki have provided students with lab-based reports that allow students to collaborate and have been helpful (Elliott & Fraiman, 2010). Additionally, students can watch a remote Instructor Point of View experiment in which the instructor wears a camera while completing the experiment (Fun Man, 2016).

Before the pandemic, few researchers focused on understanding the impacts of using these remote laboratory exercises to replace hands-on laboratory experiments. Data computation has long been a part of chemistry. Still, the literature search does not return articles that revolve around using this type of experimentation as a complete replacement for hands-on activities. The most common return from this research deals with the use of online videos and animations for prelab exercises (Gryczka et al., 2016; Jolley et al., 2016; Lamichhane & Maltese, 2019) and as supplements (Baker & Verran, 2004; Perri, 2020; Rennie et al., 2019; Starkey, 2019). Suggestions for laboratory data computation projects are also given, but not for the full-scale replacement of laboratory activities (Campbell et al., 2020; Magers et al., 2019). The author believes replacing labs with remote exercises was an uncommon technique pre-COVID and fails at a push to move away from verification chemistry to one of inquiry. More immersive, inquiry-based tools are available for remote instruction.

Robotic Laboratories

A relative newcomer to remote chemistry is using robotics to perform experimentation. Robotic tools were initially used by space and military programs to conduct experiments in hazardous environments (Kennepohl et al., 2004). The *Journal of Chemical Education* details several experiments that have been designed with the use of this type of robotic equipment.

A device connected to the Internet allowed students to do synthesis experiments and monitor them in real-time (van Rens et al., 2013). The device's inception occurred due to the hazardous nature of the many organic chemicals. In this case, the production of methyl orange, created by a highly exothermic reaction that can be explosive, was used as a basis. In another publication, an attempt to use spectrometry tools, such as FTIR and UV-VIS, were documented for use in remote instruction (Kennepohl, et al., 2004). At the time of its publication, the authors noted that further research must be conducted to make it feasible for students to use. Remote use of an NMR instrument, another form of spectroscopy, was articulated in the literature where students could seal vials and mail the chemicals in (Kennepohl et al., 2004). Students would then have remote access to the instrumentation to run their experiments.

The ubiquitous chemistry titration, the bane of many students, also moved into the robotic world (Soong et al., 2021). In one of the more interesting articles, Soong et al. created a robotic setup with a servo, a camera, and a Raspberry Pi. The system used the servos connected to an Internet-based program to open and close the stop cock on the buret. In this way, students can control a buret from the system while monitoring the buret volume and the substance being titrated. Simple experiments like those involving a strong acid and strong base were conducted. Still, more advanced experiments were also performed, such as the titration of phosphoric acid in Coca-Cola. The authors noted that this modality might complement virtual titration experiments and allow students to see real-world errors such as fluctuations in pH and transient color change.

Robotic laboratories have several benefits. For one, students have reported that they are enjoyable (van Rens et al., 2013) and allow them to have a hands-on technique while making inquiry-based observations. In any experiment involving dangerous chemicals or procedures, safety is another significant benefit of this type of experimentation (van Rens et al., 2013). Additionaly, money can be saved on chemicals through microscale experimentation (van Rens et al., 2013). A wide variety of students from different schools may use the experimental equipment over the Internet, allowing for the pooling of funding and increasing the number of students who may not have had access to essential learning tools (Benefiel et al., 2003; van Rens et al., 2013)

The most obvious downfall of this type of remote robotic laboratory is the cost of the technology, setup, and maintenance. Another limitation is the number of users allowed to perform the experiment at a time. Students may have computer issues or instrumentation breaks down during laboratory exercises (van Rens et al., 2013; Soong et al., 2021).

Virtual Laboratories

Considered immersion technology, virtual labs are conducted entirely in a computer system (Cummings & Bailenson, 2016). These designs are often two-dimensional but have moved into the third dimension (3D) as technology has progressed. Students can work through problems and perform experiments in simulated environments with the ability to change their setting, change the level of control they possess, and make observations. Immersive virtual laboratories allow inquiry-based experiments to be conducted in a safe environment (de Jong et al., 2014). As technology has advanced, many are confident that virtual experiments can match closely with teaching and research laboratories (Makransky et al., 2016; Vrellis et al., 2016).

A virtual lab is one in which students access materials using a computer or other electronic device. For example, Labster lists 64 simulations available for chemistry. Experiments are varied. They include identifying the concentration of acid by titration or identity based on pH probe titration, Nuclear Magnetic Resonance spectroscopy to identify an unknown compound, visualization of atomic structure, carbon chemistry, and a wide variety of topics. There are also safety virtual labs such as chemical waste disposal and identification of hazard symbols. Some labs are set to be simple investigation ones, such as identifying an unknown acid, while some are geared to gamified experiments. An example of the latter would be an environmental impact experiment where you pretend to be a project manager looking at coal power plants.

The benefits of using a virtual lab are numerous. Gamification is possible with virtual lab programs like Labster and Praxilabs (Caño de las Heras et al., 2021). Virtual labs may be helpful when the cost of the experiment is prohibitive or dangerous (Zyda, 2005). Ali and Ullah (2020) summarized the benefits of virtual labs as:

- safe;
- realistic;
- accessible almost anywhere;
- able to be simplified and adjusted at the teacher's discretion;
- able to demonstrate advanced procedures and concepts;
- cost-effective;
- able to be adjusted for gamification, innovation, and the enjoyment of the students;
- effectively prepares students for hands-on experiments;
- and able to conveniently store data.

Several studies have been conducted on the effectiveness of virtual labs in chemistry. Many have concluded that virtual labs may be useful (Bortnik et al., 2017; Caño de las Heras et al., 2021; Hawkins & Phelps, 2013; Woodfield et al., 2004). For example, Bortnik noted that virtual labs are useful as a supplement in analytical chemistry, although not a replacement. Hawkins and Phelps (2013) showed no significant differences in pre-/post-testing scores or in hands-on setup evaluations between students who took a virtual lab and those who performed the lab in person. Caño de las Heras et al. (2021) noted that motivation levels were high, and there was strong engagement throughout the use of virtual laboratory exercises. Davenport et al. (2018) indicated that student outcomes were favorable when virtual labs were used in conjunction with an initial exposure to hands-on activities.

Lab Kits and Home Chemistry

In some cases, it is still possible to get hands-on experience during a remote class. This hands-on activity is often done by using at-home lab kits or materials found in the home, often called "kitchen chemistry." Lab kits are pre-generated by the school or through sites such as Caroline Distance Learning or Home Science Tools. Students are generally responsible for purchasing the kits. Home chemistry experiments use common household materials but may require students to buy specific components like balances or pH paper, as well as reagents.

The main benefit of this type of remote laboratory is that the student obtains hands-on experience. Experiments typically found in a chemistry laboratory environment can be done on the micro-scale with these kits. For example, Kennepohl (2007) developed a lab kit in which students could perform density measurements, spectrophotometry, titrations, gas law experimentations, and stoichiometry—all incredibly common experiments done in a general chemistry lab. Hoole and Sithambaresan (2003) provided materials for an analytical course that included chromatography, spectroscopy, and electrochemistry. While precision and accuracy were lower than in an in-person class, the authors noted that students could still have meaningful learning (Hoole & Sithambaresan, 2003). Kennepohl (1996) also developed a micro-lab kit that allowed solution chemistry experiments, calorimetry, and quantitative phosphorus analysis. Even organic chemistry learned in the kitchen has received attention in the literature (Pitre et al., 2021). Examples of these experiments include recrystallizing aspirin, creating pH indicators, performing extractions, and creating polymers.

A review of the literature showed generally positive outcomes when using these methods of instruction (Brewer et al., 2013; Boschmann, 2003; Carrigan, 2012; Hoole & Sithambaresan, 2003; Kennephol, 2007; Meyers et al., 2014; Phipps, 2013; Pitre et al., 2021). Kennephol (2007) indicated that students enjoyed the kits' independence and self-paced activity. Student responses also stated that the kits allowed for experimentation contextualization as it is done outside the formal laboratory. Over 71% of the students in the Pitre et al., (2021) study reported they would recommend this type of chemistry, and 62% believed it helped them better understand organic chemistry. Carrigan (2012) stated that the kits could save students money by eliminating drives and hotel stays, even though there is an upfront cost. In addition, Carrigan (2012) also wrote that both instructors and students appeared pleased with the lab kits. Students felt a high level of responsibility to complete assignments due to their financial investment.

Safety is a significant concern with home experimentation (Phipps, 2013). Safety is one of the ultimate concerns in any chemistry laboratory. Instructors are responsible for reviewing safety procedures and monitoring for safety violations. At home, students would not have this type of supervision. While they reported success during their experimentation with home chemistry, Pitre et al. (2021) noted that once their school moved back to on-campus instruction, the home chemistry program was immediately discontinued. They cited safety considerations as the main reason. In a review of the LabPaq Science Kit, Carrigan (2012) stated that the lab kits have safety equipment on top and require the students to sign a three million dollar bodily harm waiver before using the kit to protect the issuer from litigation. According to Boschmann (2013), one of the central tenants of developing distance education courses for chemistry is that chemicals must be low concentration and low toxicity. In addition, plastic should be used in place of glassware to prevent injuries.

Another obstacle to using these kits is the upfront cost. Kennepohl (2007) developed kits that cost $800 but contain almost everything the student needs (except a few household items). During Kennepohl’s study, the school provided the kits to the students. While the student doesn't take on the financial burden in this case, the school must. In another study, the commercial kits required by State Fair Community College cost $350 (Burchett & Hayes, 2017), but the cost is the student's responsibility. If a State Fair Community College student could not purchase a kit, they were removed from the course. The school went to kits developed by the college staff in 2011, but they cost $400 (Burchett & Hayes, 2017). While this allowed for a better selectivity of experimentation and adjustment of materials, the issue with students being dropped for not purchasing a kit persisted—this additional cost further disadvantaged students who could not afford the financial burden.

Emergency Remote Teaching

During the 2019–2020 academic year, the *Journal of Chemical Education* requested papers regarding lessons learned during the COVID-19 pandemic (Holme, 2020). The COVID-19 pandemic provided a unique case study. Instructors were forced into ERT and sometimes provided classes within days or weeks of the school closing its doors. As a result, teachers were forced to improvise their modalities and curricula in a way they never had before. A common saying in the Chemistry Department at El Camino College was, “anything is better than nothing.”

Elizabeth Kelley (2021b) took on the task of reviewing all of the articles that answered Holme's request for experiential papers, as well as several from other journals. Kelley's work examined the research for those that included laboratory information, mainly what instructors did during the rapid movement to online teaching, how this affected the students, and what outcomes were common. Ninety-one total articles were reviewed and acted as a starting point for my research. It would be an understatement to say that Kelley's work was instrumental in building this project and its conception.

What Instructors Did

Kelley (2021b) focused more on student outcomes in her summary article. To accomplish this, she first categorized the different types of remote instruction in the articles sent in response to the call for data. Results are summarized below and explored in detail in the subsequent review.

Kelley (2021b) created several categories for curricular adjustments during ERT. They are as follows:

- hands-on experimentation such as kitchen chemistry and at-home lab kits;
- experiments by proxy, including those that are conducted by an instructor, directed by students, or use robotic remote instrumentation;
- second-hand experiments, including non-interactive videos given to students to make observations;
- simulated experiments, such as virtual laboratories;
- sample data analysis, in which students were given pre-generated data sets to perform computations;
- extension work, or learning based solely on work done before the move to ERT without any further labs;
- planning experiments and reporting results, or the process of designing experiments, conducting formal lab reports, and giving oral presentations;
- conceptual exercise, including worksheets or practice problems that replace experiments;
- and all other endeavors, including journal readings, literature reviews, etc.

Counts were made when an instructor mentioned using a specific type of adjustment. Ninety-one articles were reviewed. Many articles mentioned multiple interventions, so they counted in different categories. For example, if a report described the use of both virtual laboratories and data analysis, counts were tallied for both. The completed tally showed 46 counts of the adjustments used secondhand experiments. This was followed up by the use of virtual reality experiments at 41 counts. Planning/communicating and firsthand experimentation followed with 32 counts and 27 counts of the total tally, respectively. Other endeavors encompassed 17 counts of the total. Extensions (5 counts) and experiments by proxy (4 counts) were the least reported.

Interestingly, replacement exercises were not included in the tally. Kelley (2021b) stated that this is because many instructors used this type of adjustment but did not directly state it in their adjustment papers. Instructors may also not have reported outcomes for this type of intervention. A small sampling of the techniques and the results are detailed below.

Qiang et al. (2020) used multiple techniques during their movement to online learning. The authors could no longer have students perform undergraduate research during the transition. Group meetings were not satisfactory, so the authors devised new techniques. Students were given literature review projects with a guiding question. Qiang et al. (2020) provided an example: "What are the main factors to consider for fabricating a polymer solar cell device with high efficiency?" (p. 3447). Students presented findings from the literature and follow-up questions added by the instructor. Students were also given projects that required relying on the *Journal of Visualized Experiments* to learn about experimental procedures. Simple home chemistry projects such as drying out contact lenses to review polymer hydrogel swelling, effects of heat and cold on rubber, and freezing point depression experiments were also used. Computational experiments were also used to expose students to programs like MATLAB. Qiang et al. (2020) reported that while the situation was challenging, they believed their students' learning was meaningful and that the lessons learned helped improve the chemical learning environment post-COVID-19.

Kelley (2021a) also submitted an article for the COVID-19 call detailing her home chemistry kit for a high school organic chemistry hands-on experience. Each kit was composed of nine different experiments. Six of the labs were identified as "cookbook" type experiments (Kelley, 2021a), and three of the experiments were meant to act as experimental design experiences. Experiment requirements included performing the experiments safely, taking pictures, uploading data, and participating in virtual discussions. Safety considerations for the lab were noted as one of the primary concerns, along with cost, relevance to material, and ease of experimentation. Hands-on experiments included typical organic experiments such as extractions, modeling, chromatography, and distillation. Kelley (2021a) stated that students generally reported positive feelings about the at-home lab and that labs felt relevant to their learning. Student performance was also indicated as being good, with high submission rates and excellent average scores on assignments.

Zuidema and Zuidema (2021) reported their lab experience while teaching a supplementary chemistry course in Jakarta, Indonesia. A primary goal in this two-week course was for students to understand the digital equipment often used in chemistry. The researchers used Zoom to meet with classes synchronously and perform experimentation as students viewed. The course covered spectroscopy experiments, cooling and freezing curves, pH sensors, electrochemistry, and computer programs such as Chemdraw. The researchers gave a brief oral introduction, then led the demonstrations. Students could also be permitted to control the digital equipment remotely, allowing for a more hands-on experience. Qualitative experiences noted by Zuidema and Zuidema (2021) indicated that overall, students enjoyed the interactivity, and the course effectively sparked interest in chemistry. The authors stated in their conclusions that while they had great results, they do not believe this type of experimentation will ever replace the experience students gain in a laboratory with hands-on activities.

Dukes (2020) detailed his experience teaching an Instrumental Analysis laboratory course while in ERT. One of the significant components that Dukes (2020) used was recycling old data. It was noted that often students did not understand where the data came from or how to use it as they had not collected it themselves. Simulations were also used for pH titrations and Beer's Law in the hopes that students would not be as confused. Dukes (2020) noted that there appeared to be a better level of understanding with students during data collection when they performed the virtual experiments. Dukes (2020) further indicated that this experience shows that students' time with the instrument before completing an experiment is instrumental in understanding what they are doing. The author also noted that simulations helped build macroscopic knowledge (how the atomic scale affects the visible scale) in chemistry. It was also pointed out that experiments must be well designed to match student learning outcomes and create student engagement. One way of avoiding gaps in understanding during laboratories is to make use of downtime by checking in with students one-on-one (Dukes 2020).

Aguirre and Selampinar (2020) detailed the experience of converting a three-semester general chemistry course to remote learning. This three-semester course was geared towards students who did not feel comfortable taking chemistry in two semesters, as was the norm. The article looked at how the entire class was converted, including both laboratory and lecture sections. The authors stated that the remote labs relied on previously generated prelab videos and quizzes, coupled with virtual laboratories created by Hayden-McNeil. Videos could not be completed on campus because the school was closed, so Youtube channels with similar experiments were used in the school's lab manual. The authors also used pre-generated data for the experiments. In terms of the experience, Aguirre and Selampinar (2020) indicated that it was necessary to remember that all students were having difficulty due to the transition. Asynchronous activities made it possible to reach a larger population of students. Yet a significant student experience portrayed by the authors showed that there was an often "uninformative learning experience" due to the lack of social contact and that some instructors simply continued to teach ineffectively even when presented with information that their students were not doing well (Aguirre & Selampinar, 2020).

During the pandemic, George-Williams et al. (2020) related their experience teaching chemistry at the University of Sydney. They decided not to use any at-home chemistry experiments due to safety concerns. Instead, they used recorded videos of experiments, dry labs (such as data plotting), and simulations. Wet lab techniques were reviewed, but students had no hands-on experience performing them. Students were also presented with a gamified version of a lab exploring protein folding called Foldit. The authors noted that some students enjoyed the experience while others were challenged by the difficulty and autonomy of the task. Like Dukes (2020), George-Williams et al. (2020) wrote that this extenuating circumstance allowed for the opportunity to review current in-class teaching methods and that perhaps this will provide an opportunity to build better in-person activities to increase student learning.

Dunnagan and Gallardo-Williams (2020) wrote about a rather unique and inventive technique for labwork to continue during ERT—the use of virtual reality. The authors had previously published a work on their VR activities developed using WondaVR (Dunnagan et al., 2020) to create an infrared spectroscopy laboratory. Four further VR experiments were designed for first-semester organic chemistry—thin layer chromatography, extraction, dehydration of alcohols combined with gas chromatography, and SN2 reactions of alkyl halides. Dunnagan and Gallardo-Williams (2020) stated that before the pandemic, the use of the VR program was limited. There was a belief by administrators that if distance education were offered to the entire student body, students would select that type of course, losing out on the traditional hands-on experience. Dunnagan and Gallardo-Williams (2020) noted the major challenges were the time to instruct teachers on using the equipment, the cost and supply of VR equipment to students, student challenges (social and economic), and the challenges of dealing with student attitudes towards the experience. Overall, the authors state that students received this type of simulation well, and the challenges were surmountable. Student outcomes were similar to previous in-person classes in a traditional lab.

As can be seen from this small sampling of the papers submitted to the Journal of Chemical Education in response to the call of ERT experiences, there is not a lot of deep qualitative or quantitative data about student experiences and outcomes. Kelley (2021b) also notes this but compiled data from the different supplementary data sets submitted by authors. Of the 91 articles Kelley reviewed, 51 provided qualitative or quantitative data via supplements. The comparison that Kelley (2021b) drew included those with performance, competencies, and engagement.

Kelley (2021b) noted several key factors in comparing student performance throughout the transition to ERT. One of these factors is how comparisons were made between students. When comparing students who were all in ERT, this was referred to as *same cohort.* The other comparison was where authors compared the current, emergency remote taught cohort and previous cohorts before the pandemic, entitled *different cohorts*. In addition, student cohorts who performed actual hands-on activities at home and those who did not were compared.

Kelley (2021b) indicated the following performance results from the information gathered. When comparing students who were all in ERT (*same cohort*), those who practiced more hands-on activities generally did better. Kelley (2021b) also noted that the results were not unanimous. There was no significant difference in performance before and after the transition amongst students in the *same cohort* designation and had hands-on training at school and during ERT. Those that had hands-on activities at school then went home to data analysis and videos, students performed worse at home, or there were no significant differences.

Comparisons were also made in terms of performance to *different cohorts*. Kelley (2021b) stated that when comparing the previous cohort, which had all hands-on activities, to one in ERT that maintained some hands-on training at home, there was little difference between them. When students in the ERT cohort had no at-home hands-on activities and were compared to previous cohorts, it was difficult to determine any notable difference in performance.

Kelley (2021b) also reviewed student competencies and the differences between cohorts. Kelley (2021b) described the results as different between technical and non-technical aspects. A technical competency refers to hands-on, psychomotor activities, data interpretation, troubleshooting errors, and procedure planning. Non-technical aspects included those that dealt with conceptual questions, engaging in presentations or writing reports.

The literature generally agrees that technical competencies suffered most during the transition. When comparing previous cohorts to the ERT cohort, there was a significant lack of understanding of data computation, increased discomfort, and poor understanding of interpretation. A common complaint from students was that they did not understand the data computation they were practicing or what purpose the computation served. Students often did not understand where the data originated. Among students compared to the same cohort, students who continued at home with hands-on activities did not significantly change competencies, including interpreting data (Kelley, 2021b).

When comparing students of *different cohorts* during remote teaching, many instructors reported no significant change in non-technical skills. In fact, the opposite was found in a few cases, particularly in which supplementary work was given in place of the labs. Some authors reported that their students could garner skills such as report writing and community outreach that they may not have done if in person.

Kelley (2021b) states that a significant reason for the loss of technical skills may be due to the students' affective domain. Kelley (2021b) speculated that students who did their own hands-on activities might have a higher investment in what they were doing than those merely watching it through a computer screen. Further, she stated that this might not be the sole reason, as many of the reviewed authors indicated that both instructors and students were trying hard to maintain a positive attitude. The social change was postulated as another reason for the decreases, though it was noted that many instructors changed their work to include social exercises such as problem-solving sessions. Kelley (2021b) appeared to blame the lack of technical skills directly on whether or not students received hands-on activity.

The third factor Kelley (2021b) reviewed was student engagement. Engagement was defined as the investment and effort directed towards learning, including cognitive engagement, emotional engagement, behavioral engagement, and social engagement. From the review, Kelley (2021b) noted that many authors stated that their students had a positive experience yet still desired the hands-on work of a lab in place of virtual activities. Students who reported unsatisfactory experiences also indicated that they would prefer the hands-on activity of an in-person lab.

Kelley (2021b) noted that most of the results from instructors were vague. To understand the effect of being placed in an emergency situation on a student's cognitive and affective aspects, ambiguous anecdotal evidence is insufficient. To this end, the MLLI will be reviewed before moving into how it is applied in terms of this work.

Meaningful Learning in Laboratory Instrument

Novak postulated that meaningful learning occurs when a student's cognitive, affective, and psychomotor domains are engaged in developmentally appropriate yet challenging ways (1993). A student’s psychomotor abilities are often evaluated in chemistry by practical exams and experimentation results (Jones et al., 2021; Gao et al., 2020;

Govindarajoo et al., 2021; Zhang & Wink, 2021). An effective way to measure both the cognitive and affective domains while still engaging psychomotor skills is through the MLLI (Galloway & Bretz, 2015a).

This tool was developed in response to Hofstein and Lunetta's review that data on the necessities of labs was sparse (Hofstein & Lunetta, 2003). Galloway and Bretz (2015a) noted that several instruments are available to evaluate student learning. Still, they wanted to focus on Novak's Human Constructivism and how it can be applied to the laboratory. Galloway and Bretz (2015a) further indicated that while other lab surveys are available, questions from previous surveys tend to relate to the new curriculum and are not about making meaningful learning.

The MLLI tool was developed to measure student cognitive and affective experiences and expectations in an undergraduate chemistry laboratory. Expectations were measured by administering the survey during the first week of the semester; experiences were measured by administering the survey post-semester. Initially, the tool contained questions related to the psychomotor domain, but they were removed due to a lack of coherence amongst interraters. It was determined that psychomotor skills are inherent to the other two. Questions were developed so that psychomotor can be taken into account via cognitive and effective questions; therefore, they were not necessary to have separate (Galloway & Bretz, 2015a). The final MLLI included 31 items on a percentage scale, ranging from 0% (Completely Disagree) to 100% (Completely Agree). The survey had 16 questions related to the cognitive domain, eight to the affective domain, and six cognitive/affective domain items. Final values were used to create a composite score ranging from 0 to 100. The composite scores were determinable for cognitive, affective, cognitive/affective, and a total value.

MLLI has seen use in several publications. After the publication of the MLLI tool's statistical confirmation, Galloway and Bretz published two follow-up experiments the same year (2015b, 2015c). In the first article (2015c), the authors administered the MLLI test six times over two years in general chemistry and organic chemistry courses. MLLI was administered pre- and post-semester for comparison. University email addresses were collected to match the experience that the students had over the two years using a longitudinal study method.

Over the two years, 61 students were evaluated. Results showed that when students started the general chemistry series, they had high expectations, but these expectations went unfulfilled cognitively and on the cognitive/affective scale. Similar experiences were indicated when students started the organic chemistry series. Galloway and Bretz (2015c) further reported that affective perceptions appeared stable over time. Some students increased while others decreased in their affective scoring, but the overall change seemed stable.

Cluster analysis and an additional qualitative assessment of the clustered groups were performed. Galloway and Bretz (2015c) stated that initial expectations did not affect cognitive perceptions but did affect the affective and cognitive/affective domains. 'Change' clusters, those who showed higher expectations and lower experiences varied in how they progressed with further expectations. This led Galloway and Bretz (2015c) to determine that previous expectations are not necessarily carried along with the student. For example, a poor experience in general chemistry does not necessarily mean the student will have lower expectations for organic chemistry.

In another study by Galloway and Bretz (2015b), MLLI was given to 15 colleges across the United States, with students in general and organic chemistry completing the survey. The study aimed to see how MLLI functioned across different domains while still gathering valuable data. Both pre-laboratory surveys and post-laboratory experience were given for the expectation/experience dynamic. Of the 9500 students responding, 3583 surveys were used for the study.

Cluster analysis showed high and low expectations clusters that turned into high and low experiences, respectively. In addition, another cluster was observed in which students between high and low expectations returned to the same experience level. Similar to the previous study, there was a fourth cluster—those with high expectations that turned into low experiences. Galloway and Bretz (2015b) stated that they did not expect to see similar results on such a large scale, but it was an interesting find. Results also showed that MLLI is applicable across different classes with students of diverse backgrounds and experiences.

Galloway and Bretz were not the only ones to implement the use of MLLI. In an attempt to improve lab experiences, Schmidt-McCormack et al. (2017) performed a multiprong investigation into whether the use of pre-laboratory instructional videos was effective. The study was mixed methods and included recording students during lab procedures, interviews, and MLLI pre/post methodology. Medial scores for affective, cognitive, and cognitive/affective domains were calculated and contrasted. Results showed a generally negative shift in students' cognitive expectations while the affective domain became more positive.

Kelley (2021b) noted that many articles submitted to the American Chemical Society journals in response to the call for COVID-19 experiences lacked any formal inquiry on the effects remote learning had on students. One article mentioned in the works was a course development article written by Jones et al. (2021). In the article, the authors describe the use of online virtual workbench experiments during ERT. MLLI was used to survey student experiences and compared to previous data. Findings were compared to previously reported values of affective and cognitive domain scores. Affective data was similar to previously reported values, while cognitive composites were slightly higher, indicating that learning goals were met during the hybrid course.

In summary, the MLLI is a robust tool, reliable under many conditions, including large-scale use. It can be used and modified to fit the user's needs, including as a pre- or post-lab evaluation of students' cognitive and affective fulfillment during their laboratory experience.

Chapter Summary

In the literature review, several subjects were evaluated. The first was Novak's Human Constructivism. While an older learning model, it has been shown to be helpful in the chemical field, especially with laboratory exercises. The continuum between inquiry and validation exercise was also researched, indicating that the definition for inquiry may be slightly convoluted, but there are definitions available and rubrics for assessing activities. Remote laboratory activities and their use in ERT situations caused by the COVID-19 pandemic were also researched. Finally, a device to measure student meaningful learning was discussed. The following section will discuss methods for data collection using the MLLI device and a modified version of the inquiry rubric.

Chapter 3: Methodology and Procedures

This chapter explains the design and methodologies of this study, including its sampling process, sample population, and analytical tools and procedures.

The purpose of this study was to evaluate chemistry students' experience during ERT at El Camino College, particularly their laboratory experimentation replacement experiences. The following research questions were developed to investigate this phenomenon:

1. In terms of inquiry, what was the significant laboratory experience for students at El Camino College during ERT?
2. Is the overall level of meaningful learning experienced by students at El Camino College during ERT similar to published literature values?
3. Was there a link between the level of inquiry and the level of meaningful learning experienced by students at El Camino College during ERT?
4. What was the phenomenological experience for students in ERT laboratory exercises at El Camino College?

Methodological Approach and Study Design

A mixed methods approach facilitated addressing the research questions. In a mixed methods study, both qualitative and quantitative data are collected (Creswell & Creswell, 2014). Mixed methods have seen an increase in popularity outside of chemistry (Ames et al., 2009; Keil & Tiwana, 2006; Koh et al., 2004, Tashakkori & Teddlie, 2010), with even a peer-reviewed journal revolving around the technique (*The Journal of Mixed Methods*). Mixed methods have also started to appear in chemistry, particularly in education (Roche Allred & Bretz, 2019; Schmidt-McCormack et al., 2017; Shultz & Li, 2016; Xue & Stains, 2020).

Creswell and Creswell (2014) noted that this type of research at the procedural level provides a better, more complete level of understanding than either of the methods could on their own. Johnson et al. (2007) laid out a set of characteristics that are important to mixed methods:

- there is both qualitative and quantitative data collected to analyze the research questions;
- there is an analysis of both forms of data;
- both procedures must be rigorous;
- both forms must be integrated into the study through merging, connecting, and embedding;
- procedures are incorporated together in data collection;
- a theory or philosophical worldview can inform it.

Creswell and Creswell (2014) denoted several types of mixed methodologies, including primary and secondary methodologies. In this work, quantitative data was the primary methodology, and the qualitative was secondary; therefore, this type of research was labeled as QUAN-qual. In addition, both types of data were collected in a single survey, meaning that this research was embedded.

Data Sources

Two different population groups were sampled during this research. The first sample population was as many chemistry instructors at El Camino as possible, each given only the IRT portion of the survey. While this population group will not be included in answering the research questions, it will help validate the inquiry questionnaire tool developed for this project.

The main population under investigation was students taking chemistry courses during ERT at El Camino College. Emails were sent to all part-time and full-time instructors at the beginning of the Spring Semester of 2022, asking to involve their students in the survey. Instructors were asked to offer students extra credit to participate in the survey. Appendix A contains copies of the emails sent to instructors.

Qualtrics was used to collect data. For the first population (instructors), only the IRT was given. The second, main population (students) was given all three components—MLLI, the IRT, and the qualitative questions as a single survey. The survey contained two additional questions at the beginning. The first question was used to sort through students who took ERT chemistry classes at El Camino and those who did not. The number of semesters online was the second. The complete survey for the instructor survey can be found in Appendix B, while the student survey can be found in Appendix C.

Data Gathering Instruments

This research collected data through a single survey using three different tools. Two quantitative tools were used. The first has been used several times in the literature—the MLLI (Galloway & Bretz, 2015a). The second was developed for this investigation, but it is based on a rubric developed by Buck et al. (2008). A literature review shows little in the ways of qualitative assessment related to the research questions, so qualitative questions were developed specifically to evaluate the experience of El Camino chemistry students.

Meaningful Learning in Laboratory Instrument (MLLI)

They MLLI survey was developed by Galloway and Bretz (2015a) as a tool to evaluate student learning based on Novak’s Human Constructivism. Under this framework, meaning is derived from the experience and how students interact with the experience (Novak, 1993). Meaningful learning is thusly based on how students feel (affective), think (cognitive), and interact (psychomotor) throughout the curriculum (Novak, 1998). While the psychomotor component is typically inherent in lab study, the cognitive and affective domains are rarely evaluated. MLLI was developed to enhance cognitive and affective experiential understanding in particular (Galloway & Bretz, 2015a).

The MLLI survey used in this work consisted of 31 items, including one indicator item. A total of 16 items measure cognitive engagement, eight measure affective engagement, and six questions measure cognitive and affective domains. Cognitive domain items were classified as those that dealt with thought only. Affective domain items were those explicitly dealing with feeling and attitude. Cognitive/Affective domain items were those that expressly contained both items. After the pilot study, the authors noted that there should be no purely psychomotor components. Since psychomotor is related to both cognitive and affective, the psychomotor domain is already inherent through the measure of the latter two.

The original survey during MLLI development was given at the beginning and the end of the semester. Each item in the original MLLI was preempted with the same setup (Galloway & Bretz, 2015a). For the pre-semester survey, the preempt was “When performing experiments in the chemistry laboratory course this semester, I expect…” The question was the same for the post-semester preempt, but ‘expect’ was removed, and some phrasing was changed to match the past tense. This was meant to reflect the tool used to measure the experience, not the expectation.

Figure 7 shows a list of the items, whether the questions are positively or negatively worded (+ and – respectively), and which domain the question matches. Questions are based on a 0% (Completely Disagree) to a 100% (Completely Agree) slider scale. Some questions were reworded since courses were online and not in a laboratory. Rewordings are shown in the last column where applicable. For example, it is assumed that students did not perform home chemistry experiments at El Camino College; therefore, words like “program” are added to the question. Categories are abbreviated as C for the cognitive domain, A for the affective domain, and C/A for both the cognitive and affective domain. The prompt was rewritten to match this study's ERT situation and online laboratory experience.

Table 1

Questions, Categories, and Rewordings for MLLI Instrument

While performing chemistry laboratory experiments in an online environment, I…

Item	Category	+/-	Question	Reword
1	C/A	+	Learned chemistry that will be useful in my life.	
2	A	-	Worried about finishing on time.	
3	C	+	Made decisions about what data to collect.	
4	C/A	-	Felt unsure about the purpose of the procedures.	
5	C	+	Experienced moments of insight.	
6	C	-	Was confused about how the instruments work.	Was confused about how the instruments/programs work.
7	C	+	Learned critical thinking skills.	
8	A	+	Was excited to do chemistry.	
9	A	-	Was nervous about making mistakes.	
10	C	+	Considered if my data makes sense.	
11	C	+	Thought about what the molecules are doing.	
12	C/A	-	Felt disorganized.	
13	A	+	Developed confidence in the laboratory.	
14	C/A	-	Worried about getting good data.	
15	C	-	Thought the procedures to be simple to do.	
16	C	-	Was confused about underlying concepts.	
17	C	+	“got stuck” but kept trying.	
18	A	-	Was nervous about handling chemicals.	Was nervous about employing the program or performing experiments at home when applicable.
19	C	+	Thought about chemistry I already know.	
20	C/A	-	Worried about the quality of my data.	
21	A	-	Was frustrated.	
22	C	+	Interpreted my data beyond only doing calculations.	

Item	Category	+/-	Question	Reword
23			TEST STATEMENT: Please select 60 percent for this question.	
24	C	-	Focused on procedures, not concepts.	
25	C	+	Used my observations to understand the behavior of atoms and molecules.	
26	C	+	Made mistakes and tried again.	
27	C/A	+	Was intrigued by the instruments.	Was intrigued by the instruments/programs used for laboratory assignments.
28	A	-	Felt intimidated.	
29	C	-	Was confused about what my data meant.	
30	A	+	Was confident when using equipment.	Was confident when using equipment/programs.
31	C	+	Learned problem-solving skills.	

MLLI is a proven instrument and has been used several times in the literature (Altowaiji et al., 2021; Jones et al., 2019; Galloway & Bretz, 2015b; Galloway et al., 2016; George-Williams et al., 2019; Hensen & Barbera, 2019; Jones et al., 2021; Schmidt-McCormack et al., 2017). The initial MLLI instrument was piloted and revamped to obtain 100% agreement on coding individual cognitive, affective, and cognitive/affective items during its creation. After initial application, a complete study was conducted on 436 general chemistry (GC) students and 178 organic chemistry (OC) students in the pre-/post- fashion (Galloway & Bretz, 2015a).

Cronbach α and Ferguson's δ were conducted on both the pre- and post-test during the creation of MLLI (Galloway & Bretz, 2015a). Cronbach α reliability is meant to measure the internal consistency of a Likert scale system with a desirable threshold of greater than 0.7. For both pre-test and post-test, the cognitive and affective domains were greater than 0.7, yet cognitive/affective domains were all between 0.6–0.63, indicating a questionable internal consistency. The authors explain that this is most likely a result of the cognitive and affective domains are not linked in a student's mind. Galloway and Bretz (2015a) note that students tend not to draw a connection between what they are feeling and how they are learning. Students generally view cognitive and affective domains as two separate entities. The α did indicate consistency and, therefore, reliability. Ferguson's δ helps measure test discrimination, comparing the measure of distribution across a possible range. Accepted values for Ferguson's δ are greater than 0.9. MLLI maintained a value of 0.96 during its final pilot.

Further validity testing included student data interpretation (Galloway & Bretz, 2015a). The authors of the work interviewed students to understand their interpretation of the questions in the survey. The validity test helped identify and confirm which category items belong– cognitive, affective, and cognitive/affective. Galloway and Bretz (2015) also conducted exploratory factor analysis (EFA). They noted that using positive and negative questions can potentially confound EFA results. Instead, the EFA was beneficial in denoting situations in which students could not connect with thinking and feeling while working in the laboratory. EFAs commonly show response patterns, and during this evaluation, showed that students were unaware of their thoughts and feelings during laboratory experimentation.

Vetted and tested, MLLI provided an excellent tool for this study. No study was performed before El Camino College went into ERT, so only a post-evaluation was conducted. A single data collection setup using MLLI is not unprecedented and has been noted in the literature before (George-Williams et al., 2019; Jones et al., 2021). In addition to the MLLI survey, this study will utilize a new survey developed to assess perceived levels of inquiry.

Inquiry Rubric Tool

When El Camino College went into ERT, instructors could conduct laboratory exercises as they saw fit. During the first semester of ERT, faculty were offered Labster, a virtual laboratory program, for free. An informal survey of full-time faculty indicated that they used previous data and already produced videos in place of laboratory experimentation. It is unknown what part-time faculty members did. The large allowances made for a wildly different experience for students during ERT, particularly regarding validation and inquiry experimentation. Students may not even have had a laboratory component.

A new system was devised for this study to assess what level of inquiry students experienced during ERT at El Camino. It was based on the rubric created by Buck et al. (2008). In the literature rubric, instructors would look at individual experiments and rate six items on whether they were provided to the student or if they had to determine it themselves. The rubric provides for five different levels of inquiry: confirmation, structured, guided, open, and authentic. For the purposes of this study, *confirmation* was renamed to v*alidation,* and a*uthentic* was renamed as f*ull*.

To determine the original rubric's validity, the three authors of Buck et al. (2008) compared three laboratory manuals with 36 various activities against this rubric. At the conclusion of their review, there was an inter-rater reliability value of 83% agreement, above the 70% that the researchers deem to be the minimum value (Buck et al., 2008).

The limitation of this rubric for this work was that it is designed to evaluate individual experiments reviewed by a panel of instructors. While it is a validated tool (Buck et al., 2008) and used by others in the literature (Bowen et al., 2018; Bretz et al., 2016; Cuartero & Crespo, 2018; Gao et al., 2020, Goeltz & Cuevas, 2021), the research questions of this study aimed to understand students' overall lab experience, rather than experiences with individual experiments. This rubric would not be able to measure other factors in a student's experience.

For example, students may have taken multiple courses with different instructors; instructors may have changed their teaching techniques; students often forget which separate experiments they conducted.

The author designed a quantitative method to complement this rubric. The rubric components dictated by Buck et al. (2008) were converted into questions. Students rated items with a 0–100% scale similar to the MLLI items, which are also part of the survey. For the scale, 0% will represent *Never*, and 100% will represent *Always*.

Table 2 shows the standard rubric item and the corresponding survey question. Each question was preempted similar to the MLLI components and related to the student's time in ERT with online laboratory experiments. The table also shows the levels of inquiry based on Buck et al.'s (2008) rubric and whether they are provided (P) or not provided (NP) to the student.

Table 2

New Inquiry Level Assessment Tool Questions and Levels of Inquiry Based on Responses

Item	Question	Level 0 (Validation)	Level ½ (Structured Inquiry)	Level 1 (Guided Inquiry)	Level 2 (Open Inquiry)	Level 3 (Full Inquiry)
Problem/Question	How often were the purpose and ultimate task of the lab given to you?	P	P	P	P	NP
Theory /Background	How often was the background knowledge described for experiments?	P	P	P	P	NP
Procedures/Design	How often were the procedures/directions given to you during experiments?	P	P	P	NP	NP
Results Analysis	How often were you told how to interpret the experimental results once data was collected?	P	P	NP	NP	NP

Item	Question	Level 0 (Validation)	Level ½ (Structured Inquiry)	Level 1 (Guided Inquiry)	Level 2 (Open Inquiry)	Level 3 (Full Inquiry)
Results Communication	How often were you told how to communicate the results of the experiment?	P	NP	NP	NP	NP
Conclusions	Before beginning an experiment, how often did you know the expected answer?	P	NP	NP	NP	NP

In addition, to keep students from convoluting questions due to lack of understanding, examples of 0% and 100% were given. Models ensured that students who may not understand the inquiry theories have proper guidance. For example, a student may look at the question “How often was the purpose and ultimate task of the lab given to you?” and rate it low if they think their instructor did not cover the reasoning for the lab. The purpose of the question is to ascertain whether or not the student came up with the problem or if it was given to them via the instructor or a lab procedure. The survey provided high and low examples for each question to prevent interpretive fallacies. The models are shown with their corresponding questions in Table 3.

Table 3

Inquiry Tool Examples to Aid in Understanding Question Responses

Question	0% Example	100% Example
How often were the purpose and ultimate task of the lab given to you?	You always had to come up with an experiment on your own. You decided what technique and experiment you would perform.	You were always given questions to answer for the lab. You were told what you were doing through lab procedure or lecture.
How often was the background knowledge described for experiments?	You had to look up how the experiment is performed and what theory is involved. You had to look through the literature to determine this.	You were provided with some type of background information. This may have been in your book or on the lab procedure.

Question	0% Example	100% Example
How often were the procedures/directions given to you during experiments?	You were told what needed to be investigated but had to research a proper procedure or come up with one on your own.	You were always given a list of procedures and steps to perform the lab, whether dry, virtual, or wet.
How often were you told how to interpret the experimental results once data was collected?	You had to figure out how to interpret the results on your own. There was no guidance given in the procedure.	You were given a series of steps to perform calculations. You were told what to do to figure out what the results meant.
How often were you told how to communicate the results of the experiment?	You came up with a series of results and had to figure out precisely what it meant and how to communicate them.	You were given problems/questions to answer based on your results.
Before beginning an experiment, how often did you know the expected answer?	Your work had an unknown component to it.	You knew you were supposed to get a specific value from your calculations.

Qualitative Questionnaire

A qualitative, semi-structured series of questions were added to the MLLI and IRT to fully encapsulate the experience of El Camino students in chemistry courses during ERT. Questions were chosen to match the research questions. While semi-structured, the questions were left open to student interpretation to understand what students went through and their thoughts.

The qualitative question series was kept short in length and number to keep participants from getting overburdened. Questions were broken down into two different categories—experience and inquiry. Qualitative questions were meant to act as complementary to the quantitative work. Inquiry-based questions help answer the first research question and support the new IRT. Experience questions helped answer the fourth research question and shed light on students' feelings during the COVID-19 pandemic and online classes.

Table 4 shows the semi-structured questions developed for this work. Questions were determined from experience teaching online during the pandemic. Having first-hand experience teaching, talking with students, and evaluating them through the ERT process provided unique insight. In addition, questions in the Inquiry Rubric and MLLI were used as guides. Table 4 also indicates the category associated with the question.

Table 4

Qualitative Questions and General Category Associated with the Question to Differentiate Between the Level of Inquiry Experienced by the Student and What Their Experience was During ERT Laboratory Instruction

Question	Category
Describe your overall experience doing chemistry laboratory experiments while online.	Experience
What types of experiments did the instructor(s) give you to do (e.g., worksheets, interactive demos, take-home kitchen labs, etc.)? What were your thoughts on them?	Inquiry
Describe an enjoyable experience you had during online chemistry experimentation.	Experience
Describe an unenjoyable experience you had during online chemistry experimentation.	Experience
How much input did you have on what experiments were conducted and how they were conducted? Tell about the experience.	Inquiry

These three tools completed the full student survey. There was a need to establish internal validity with two new tools and a tempered one. This will be covered in the next section.

Validity

Validity is an important factor when developing a mixed methods approach. Dellinger and Leech (2007) looked at unifying a framework to validate mixed methods. One of the authors' notes is that the system should be open. In the rubric developed by Dellinger and Leech (2007), quantitative and qualitative are treated separately and overlap. The use of the rubric allows for interchange between the types of validation and composite validation. With this idea in mind, the following approach was developed to validate the tools used in this work.

For the qualitative portion of the survey, the questions were first submitted to all full-time instructors at El Camino for review. Given that this is a single researcher's work, reaching out to fellow instructors who went through similar situations in ERT at El Camino College was beneficial. It helped to eliminate instructor bias from the questions. Instructors were also asked for input on questions and whether they were sufficient. Onwuegbuzie and Leech (2007) described this type of peer debriefing. It allowed knowledgeable individuals to play "devil's advocate" on the qualitative questions to ensure the most robust experience was obtained with the research questions in mind.

Responses in the qualitative portion of the survey were open-coded. Since there is only one author, there is a possibility to further bias. To compensate for the single author, a second El Camino chemistry instructor performed coding of the qualitative results. A goal of 70% was set for coding agreeance.

In addition, during the first phase, instructors at El Camino were asked to take the IRT related to their online teaching methods. Cronbach α was applied to these results. Results were compared to literature-determined values using the traditional rubric (Bretz et al., 2016; Buck et al., 2008). These articles show most of the courses as Inquiry Levels 0, 0.5, and 1. Qualitatively assessing similarities between literature and received values will add a layer of validity.

While MLLI has already been shown as a useful tool, its validity was confirmed during this work. Once the complete survey was administered, Cronbach α was used on the IRT and the MLLI components separately. A two-sample *t*-test was used between the instructor IRT results and those of the students to test for mean differences.

Triangulation acted as a final layer of validity for the study. In doing so, data from various sources was used to study a phenomenon (Denzin, 1978). This technique has several benefits, as described by Jick (as cited by Onwuegbuzie & Leech, 2007), including allowing researchers to be surer of their results, deriving novel methods to obtain information, and decomposing contradictions. In this case, using Pearson correlation, inquiry-based qualitative questions were compared to the IRT results and items 3, 4, 7, 22, and 31 from MLLI. These MLLI items all have an inquiry component to them. Further triangulation was performed with the qualitative data based on experimental types indicated by students.

Special care was taken to ensure the validity of this study. The results could affect how El Camino College does chemistry online and in-person. All results for validity testing are shown in Chapter 4. With methods for validity established, the following section covers how data was processed.

Data Processing

After validation, data processing was conducted. Before calculations began, an initial processing to purge inappropriate data happened. One of the first questions students came across in the survey asked if they took online chemistry courses at El Camino College. If the student answered no, their data was removed. Further, the MLLI questionnaire has an item asking students to select the number 60 to identify participants who randomly answer the survey. Data sets that do not have this item correctly were removed. Incomplete data sets were also removed.

The IRT was processed twice. The first assigned an overall quantized experience of 0, 0.5, 1, 2, or 3 in terms of their level of inquiry. This was done by assigning a *P* (provided) or *NP* (not provided) based on student answers between 0–100%. Any responses above 50% indicated that the student was generally supplied with the material in question and denoted with a *P*. The rubric was then used to determine their overall experience. This was titled

Whole Number Rubric Score. An error was noted when a data set did not fall under any rubric scores.

In addition, the percentage that students reported was reversed and divided by 100 to become a fraction. A weighted average equation was applied, shown below (2). The equation weights items e and f less, as having these two items 'non-provided' gives the first rubric item a score of 0.5. Similarly, going from a rubric score of 2 to 3 requires both items a and b to be 'non-provided,' so, therefore, they are weighted differently. This score was the Fractional Inquiry Score.

$$FRS = 0.5a + 0.5b + 0.75c + 0.75d + 0.25e + 0.25f \quad (2)$$

For example, if a student presented the results in Table 5, the following calculations would be done. Each component over 50% was scored as Provided using the Whole Number Score and those under 50% as Not Provided. Using the rubric would rate the students' overall experience as 0.5, which is Structured Inquiry. Using the Reversed Fraction, individual Fractional Inquiry Scores for each item are calculated and summed. This gives a value of 0.71. Reviewing the rubric places it between Structured Inquiry and Guided Inquiry, which is more closely related to Structured.

Table 5

Example Calculation for Both the Fractional Inquiry Score and Whole Number Score

Item	Question	Reported Score	P/NP	Reversed Fraction	FRS Score
a	Problem/Question	98%	P	1 - 0.98 = 0.02	0.01
b	Theory/Background	97%	P	1 – 0.97 = 0.03	0.015
c	Procedures/Design	100%	P	1 – 1 = 0	0.00
d	Results analysis	57%	P	1 – 0.57 = 0.43	0.3225
e	Results communication	45%	NP	1 – 0.45 = 0.55	0.1375
f	Conclusions	10%	NP	1 – 0.10 = 0.90	0.225

Results from the MLLI component were calculated, as done in the literature (Galloway & Bretz, 2015a). Averages of cognitive, affective, and cognitive/affective responses per student were calculated. Averages overall for each domain were also calculated. Finally, an overall meaningful learning score was computed based on an average of the processed MLLI data. These values and those determined from the IRT were used to evaluate the hypothesis postulated in Chapter 1.

The IRT was used to answer hypothesis A, which is shown below:

- H_{o1}: There is no difference between the level of inquiry students experienced during ERT at El Camino College.
- H_{a1}: There is a difference between the level of inquiry students experience during ERT at El Camino College.

Two different tests were performed to evaluate the hypothesis. Values were tested using the Shapiro-Wilk test. A normal distribution would indicate a difference in inquiry levels experienced by students, thereby rejecting null H_{o1}. To support an understanding of the level of inquiry, a two-tailed Wilcoxon signed-rank test was applied to determine if there was variation in the data compared to the literature values (Buck et al., 2008).

Once survey data was computed, the results from the MLLI survey were compared against the literature to answer research question 2. This was used to test hypothesis B, shown below:

- H_{o2}: There is no statistical difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values.
- H_{b1}: There is a significant difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values.

To test hypothesis B, a series of two-sample t-tests were performed to possibly reject H_{o2} by comparing student responses in this study to literature values (Galloway & Bretz, 2015a; Enneking et al., 2019; Jones et al., 2021).

Internally, IRT and MLLI values were compared to answer research question three. These research questions relate to hypothesis C, which is shown below:

- H_{o3}: There is no link between the level of inquiry reported by students and the overall level of meaningful learning experienced by El Camino College.
- H_{c1}: There is a positive link between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.
- H_{c2}: There is a negative correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.

Plots of Fractional Inquiry Scores as a function of cognitive, affective, cognitive/affective, and an average of all three were compiled for qualitative assessment. Pearson's r was calculated to determine if there was a link between Fractional Inquiry Scores and individual MLLI components to evaluate hypothesis C.

Two separate individuals coded the qualitative data as indicated in the validity portion. Coding was done in a primarily open fashion, using Tesch's (1990) eight-step process. In this fashion, codes were emergent depending on trends found in the qualitative data. Overarching experiences were noted and relayed in Chapters 4 and 5.

Some codes were already expected, though. Creswell and Creswell (2014) note three different types of codes—expected codes, surprising codes, and codes of unusual or conceptual interest. Expected codes include levels of inquiry, experimentation types, and positive/negative experiences. As qualitative data was collected and reviewed, a codebook was generated. Chapter 4 shows an annotated version of the codes, and Appendix D contains the coders' complete codebook. Counts were noted for each code. Comparisons to values found in MLLI and the IRT were performed and contrasted to find the experience chemistry students had at El Camino College while in ERT. In addition, as data was reviewed, further tests were conducted to elucidate the experience students had during ERT, as described in Chapter 4.

Human Subject Considerations

Data collection took the form of a survey given to both instructors and students, so human subject safety considerations must be considered. Surveys were provided via Qualtrics and password-protected to only a single investigator. Downloaded data was saved on an encrypted backup system, only available to the primary investigator.

Instructors received the first survey (Inquiry Rubric only) as a Qualtrics link via email. Instructors were given no incentives aside from asking to aid in building on the knowledge base. The second survey Qualtrics link was sent to instructors via email but separately. Instructors were asked to give students who took the survey extra credit. In the formal, complete survey, students were given an opportunity to indicate they took the survey. After the survey, an outside link was available to type in their email and select their current instructor via Google Forms. This way, emails were collected without data attachment, meaning the data could stay anonymous. This will minimize the chances of influence on results or backlash against students for honesty in their responses.

In addition, the survey started with a brief introduction to the research. Survey takers were asked to confirm that they were over 18 and agreed to participate in the study as part of informed consent. Participants were informed that their data would be processed anonymously, and no data was reported to their instructors. The purpose of the study was described. Participants were also informed that they may stop taking the survey at any time.

Risks and an approximation of how long the survey will take were also noted. In this way, students were provided informed consent on whether to complete the survey. Since there was no hazard outside the context of taking the survey, according to the U.S. Code of Federal Regulations, DHHS (CFR), Title 45, Part 46.117, no written documentation of informed consent was necessary, and the initial indicator questions were sufficient. A gateway informed consent question was still added, and anyone indicating they refused the survey guidelines were removed from the data set. Appendix E contains the full informed consent.

U.S. Code of Federal Regulations, DHHS (CFR), Title 45, Part 56 provides guidance for human subject considerations. No protected groups were under research as part of this study. The survey did not use deception, and the risk to subjects was minimal. Therefore, this study qualified for exempt research application survey subjects (Pepperdine IRB, 2018). IRB approval requests were submitted to both Pepperdine University and El Camino College and received from both. IRB approval from Pepperdine University can be found in Appendix F.

Chapter Summary

This chapter describes the methods for surveying student experiences with chemistry laboratories during ERT at El Camino College. A new tool, the IRT, was used in conjunction with a tool previously discussed in the literature—the MLLI. In addition, qualitative questions were asked to build a detailed picture of what students encountered while taking laboratory classes online. Data processing was extensive to ensure validity and test hypotheses. Human considerations were also covered and shown to be of minimal risk.

Chapter 4: Results

Introduction

This study examined El Camino students who took classes during ERT due to the COVID-19 pandemic, focusing on their chemistry laboratory experience. The study addressed four research questions:

- Research Question 1 (RQ1): In terms of inquiry-based learning, what was the laboratory experience for students at El Camino College during ERT?
- Research Question 2 (RQ2): Is the overall level of meaningful learning experienced by students at El Camino College during ERT similar to published literature values?
- Research Question 3 (RQ3): Was there a link between the level of inquiry and the level of meaningful learning experienced by students at El Camino College during ERT?
- Research Question 4 (RQ4): What was the phenomenological experience for students in ERT laboratory exercises at El Camino College?

The study tested the following hypotheses that correspond to these RQs:

- H_{o1}: There is no difference between the level of inquiry students experienced during ERT at El Camino College.
- H_{a1}: There is a difference between the level of inquiry students experienced during ERT at El Camino College.
- H_{o2}: There is no statistical difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values.
- H_{b1}: There is a significant difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values collected.

- H_{o3}: There is no correlation between the level of inquiry reported by students and the overall level of meaningful learning experienced in laboratory exercises by El Camino College students during ERT.
- H_{c1}: There is a positive correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.
- H_{c2}: There is a negative correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.

During the spring semester of 2022, students in chemistry classes had the opportunity to participate in a survey developed to answer these questions. The survey consisted of three different sections. The first consisted of six Likert-like questions to determine the level of inquiry a student experienced (The IRT). The second involved 30 Likert-like questions related to the student's level of meaningful learning during ERT (MLLI). The final component of the survey asked the respondents five open-ended questions related to their experience.

This section presents the results of this three-part survey. Instructors took the IRT survey separately to aid in validation with results also shown in this chapter. Results from the surveys, including descriptive analytics and notation of results that support or reject the study's hypotheses, are shown. In addition, emergent results meant to aid in the development of overall understanding will be noted.

Data Processing

Data collection happened from March 25th until April 25th, 2022. Two different surveys were sent to instructors—the IRT for instructors only and the three-part full Student Survey. First, instructors completed only the IRT questions. Instructors were asked to share a full survey link with their students in the second. Eleven instructors completed the IRT, and 125 students completed the entire survey.

One data set was removed from the instructor survey due to incompletion. Several data sets were removed from the student survey. Eighteen data sets were removed due to incompletion. One data set was removed because the student did not grant consent. Thirty-five data sets were removed because the students indicated they did not take any online chemistry courses. Two data sets were removed because they did not appropriately complete the MLLI test question. With these data sets removed, the final total resulted in 69 quantitative data sets processed, as described in Chapter 3. All identifying information was removed, and each student was assigned a number from 1 to 69.

In the Informed Consent, students were instructed they did not need to complete any portion of the survey where they felt uncomfortable. Their results were still kept when students completed the quantitative data portion but did not fully complete the survey. From the 69 data sets, four students did not complete the qualitative part of the survey.

Data Coding

Once data compilation was complete, two independent faculty members (the researcher and a full-time chemistry instructor at El Camino College coded the qualitative data. Interrater agreement was 95%, well above the desired 70% threshold. The codebook used by the coders can be found in Appendix D. Codes are divided into six categories—Overall Experience, Feelings, Community Experience, Material Experience, Types of Instruction, and Input in Lab. The following section will detail each of these codes. In addition, the codes that fall under each category will be shown in tables. Tables include the code, the meaning of the code, an example from the qualitative data corresponding to the code, and the total count. Total counters refer to the number of times the code was used and may be present more than once for a given student. During data computation, codes per student were also kept track of for emergent calculations. These results are discussed in another section of this chapter.

The Overall Experience category shown in Table 6 included codes related to how the students perceived their laboratory experience more broadly. These codes included likes and dislikes of the laboratory experience rather than more subjective reflections. Codes included students noting the flexibility of the online experience and some indicating that they felt the work was easy. Other students suggested that the laboratory assignments were confusing or complicated. Codes were also created when students indicated they could or could not relate the material to what they were doing in lecture and future work. Finally, a code was developed when students expressed a complete lack of learning or lack of learning important information during their laboratory assignments.

Table 6

Overall Experience Codes, Examples, and Count for Qualitative Data

Code Name	Code Description	Example	Count
Flexible	Students could work independently, build their schedules, and do work at their own pace.	Student 27: …but I did enjoy learning at my own pace and not rushed	9
Easy	Work was easy, simple, or effortless to complete.	Student 21: Laboratory experiments while online were very simple to do.	22
Relating/Relevance Positive	Students could relate the work assigned as laboratory work to either lecture or future work. This code also refers to cognitively engaging with the work and understanding what they were doing.	Student 44: Mentally connecting pieces of information with the help of interactive demos and videos.	11
Relating/Relevance Negative	Students could not connect with the laboratory work and relate it to lecture or future work.	Student 41: I did not really learn how to properly identify and use lab equipment.	29
Confusing	Students stated they were confused by the material, did not understand what they were doing, or were confounded by the work.	Student 35: Very difficult and confusing.	36
Difficult	Students found the laboratory work to be complex, challenging, or demanding.	Student 52: It's challenging through online…	16

Code Name	Code Description	Example	Count
Information Not Important	Students indicated that they were learning nothing or that the information they were learning wasn't relevant.	Student 24: I learned almost nothing.	12
Time Issues	Students expressed that they had issues with time – the class went too fast, they felt rushed, and they did not feel they had enough time to complete the assignments.	Student 42: Stress with keeping up with lectures and labs.	8

Another of the experiential code categories derived from the qualitative data was the Material Experience. This is different from Overall, as this category's codes included those explicitly related to the material itself. Codes had students' positive feelings regarding the visual representations used in labs and the ease of use working on a computer or presenting the material. Codes also included situations where students did not understand where the data came from, thought that the materials were low quality, or at its worst, did not have a single good experience with the material. Table 7 shows a compilation of these codes, a brief description, an example, and the count for a particular code.

Table 7

Material Experience Codes, Examples, and Count for Qualitative Data

Code Name	Code Description	Example	Count
Enjoyed Visuals	Students expressed that they liked the visuals, whether they were watching the instructor, visualizations in virtual labs, or experiments shown on video.	Student 1: Seeing the experiments were still very interesting.	9
Ease of Use	Students felt materials were easy to use, accessible, or didn't worry about making errors that are likely in person.	Student 27: … not so focused on making mistakes.	13
Lack of Data Understanding	Students note they did not understand where the data came from, how it was used, or its importance in their learning.	Student 40: We would sometimes just collect data and not even do post lab questions so I didn't even know why I gathered that data.	5

Code Name	Code Description	Example	Count
Low Quality Materials	Students state that the videos they watched were low quality or the programs used didn't work well.	Student 16: … unenjoyable for me because some of the reactions weren't visible enough for me to notice anything about them in the video.	17
No Good Experience	Students explicitly state that they had no positive experience working online with laboratory materials.	Student 9: (Regarding positive experience) I didn't have any.	23

The next experiential category for codes dealt with students' community experience while in ERT in their online chemistry courses. Two major sets of codes were determined from the qualitative data: when a survey taker mentioned their instructor and a set of codes related to working with survey taker peers. Both positive and negative codes were noted for both aspects. Codes, examples, and counts for the community experience are shown in Table 8.

Table 8

Interpersonal Experience Codes, Examples, and Count for Qualitative Data

Code Name	Code Description	Example	Count
Positive Instructor Experience	Students state that their instructor had a positive influence, enjoyed what their instructors did, or felt supported by their instructor.	Student 54: However the teacher was very accommodating.	2
Negative Instructor Experience	Students relate that they had negative experiences with their instructor. This could be a lack of presence, slow to respond, or a feeling of the instructor not being present for them.	Student 46: It's quite frustrating when no one is around to help you especially when they are not good at math or science.	20
Positive Group Experience	Students write about positive influence during group work or when working with their peers.	Student 34: I enjoyed working with my lab group.	15
Negative Group Experience	Students note that they had a negative experience with their groups or when forced to work with peers.	Student 65: I had unenjoyable experiences in all labs because my group would not work well together…	8

Specific emotions were also given a different code. In this category, codes were assigned to qualitative answers describing feelings students related to their experience performing laboratory exercises online. Four codes were placed into this category. They included both the positive and negative expressions of experiences. Positive feelings are described as happiness, fun, excitement, or joy, while negative experiences are related to frustration, boredom, and anger. Another code in this category was derived from students expressing their desire for hands-on activity. The final emergent code in this section relates to when students expressed that they understood that instructors were doing their best due to the COVID-19 pandemic. Table 9 shows the unique codes, a brief description, an example, and the count of individual codes.

Table 9

Student Feeling Codes, Examples, and Count for Qualitative Data

Code Name	Code Description	Example	Count
Positive Experiences	Student relates positive experiences with online learning—mentions happiness, excitement, enjoyment, and similar positive feelings.	Student 51: Overall, my lab experience online was delightful.	23
Negative Experiences	Student expresses negative feelings towards an online learning experience—frustration, boredom, hate, and lack of motivation.	Student 37: Chemistry experimentation was confusing, so frustration would arise when I would have to rewind a Youtube video to obtain data.	43
Desire for Hands-On Experience	Student explicitly states they wished for a hands-on experience or that things would have been different or preferable in a hands-on learning environment.	Student 8: … as it felt as though it took longer to grasp the concepts when you couldn't physically perform the lab.	29
COVID-19 Understanding	Students expressed that they understood their experience may have been poor due to the COVID-19 pandemic. Also coded when students noted their instructor did the best they could under the circumstances.	Student 65: It didn't feel like an actual lab experience, but given the conditions of the time period, it was understandable.	7

The following coding category related to the types of assignments students received labeled as laboratory exercises. Instead of a selection list as part of the survey preamble, this question was posted as a qualitative to invoke responses from students related to which assignments were most memorable to them. This is one of the few sections with pre-planned codes, though there were emergent ones. Table 10 shows the experiment codes, an example, and the count.

Table 10

Laboratory Activity Codes, Examples, and Count for Qualitative Data

Code Name	Code Description	Example	Count
Watching Instructor	Student states the videos they watched explicitly had their instructor present in them. This could be prerecorded or live.	Student 1: My teacher did the experiments, and we just observed.	3
Videos	Student states that watching videos was a component of their laboratory experiences.	Student 62: … and we filled them out using the data we got from YouTube videos.	39
Data Computation	Student states that they were given data sets in lieu of performing experiments.	Student 57: … or the data was already given to us.	12
Worksheets	Student relates that experiments were replaced with worksheets.	Student 10: Worksheets …	40
Interactive Labs	Students state that they were given programs, websites, or similar interactive activities.	Student 65: Our labs consisted of interactive demos…	5
Actual Experimentation	Student indicates that they had hands-on experiences while in ERT. This can include kitchen chemistry or other hands-on activities.	Student 31: … take home labs…	19

The final coding category was mainly used for the last qualitative question (How much input did you have on what experiments were conducted?) and dealt with the level of control students exerted. Codes were developed regarding whether students had no input, a little bit of input, or felt they had a lot of input in what experiments were conducted. Table 11 shows the codes, examples, and counts.

Table 11

Level of Control Codes, Examples, and Count for Qualitative Data

Code Name	Code Description	Example	Count
No Input	Student states they had no, almost nothing, next to nothing, or similar statements regarding their input level.	Student 40: We had no input.	52
Some Input	Student writes they have some input on what experiments were conducted for laboratory experiments.	Student 41: … There were times where we had to figure out by ourselves what to do, but it was easy to fix through trial and error.	6
Lots of Input	Student indicates they had a lot of input on what experiments/activities were performed instead of an in-person laboratory experience.	Student 67: I had a decent amount of input, and they were conducted by following the procedures.	3

Through emergent coding, 30 different codes were developed. In total, 641 codes were applied to 65 students' responses to the five qualitative questions. The following sections will discuss the connection of these results and their application to the study's validity.

Validation of Quantitative Data

Quantitative data was checked for validation in several ways. Validation was particularly important for the IRT developed for this study. Validation of responses is vital to answering the questions to know whether results can be applied to support policy change at El Camino College.

The Cronbach's alpha test was the first validation test applied to the instructor and student data collected in the IRT and MLLI results. The Cronbach's alpha test measures internal consistency often used for Likert and Likert-like scale items. The Cronbach's alpha coefficient was evaluated using the guidelines suggested by George and Mallery (2018) where < 0.9 is excellent, > 0.8 is good, > 0.7 is acceptable, > 0.6 is questionable, > 0.5 is poor and < = 0.5 is unacceptable.

The instructor-only data for the IRT had a Cronbach's alpha coefficient of 0.67, indicating questionable reliability. The student data for the IRT had a Cronbach's alpha coefficient of 0.86, indicating good reliability. Table 12 shows the results from Cronbach's alpha testing.

Table 12

Reliability Table for Instructor and Student IRT Data Sets

Scale	Number of Items	α	Lower Bound	Upper Bound
Instructor	6	0.67	0.42	0.92
Student	6	0.86	0.82	0.90

For the MLLI, Cronbach's alpha was calculated separately for Cognitive, Affective, and Cognitive/Affective questions. Questions #2, #4, #9, #12, #14, #15, #16, #18, #20, #21, #24, #28, and #29 were reverse calculated due to the negative nature of the question as per Chapter 3 calculations. MLLI Question #23 was removed as it is a test question to ensure survey takers are reading questions. For the cognitive questions, Cronbach's alpha was 0.75, indicating acceptable reliability. For the affective questions, Cronbach's alpha was 0.60, indicating questionable reliability. For the cognitive/affective questions, Cronbach's alpha was 0.66, indicating questionable reliability. An overall Cronbach's alpha for the MLLI was also calculated. It was 0.83, indicating good reliability. Galloway and Bretz (2015a) calculated Cronbach's alpha during the creation of the MLLI instrument and reported cognitive as 0.76, affective as 0.80, and cognitive/affective results as 0.60. The results from this work are reasonably similar to those of Galloway and Bretz (2015a). The results of the reliability testing are shown in Table 13.

Table 13

Reliability Table for the MLLI Data Sets

Scale	Number of Items	α	Lower Bound	Upper Bound
Cognitive	16	0.75	0.69	0.82
Affective	8	0.60	0.49	0.72
Cognitive/Affective	6	0.66	0.55	0.76
Overall	30	0.83	0.79	0.88

Initial validity for the tests shows fair values overall for the survey. Questionable values in the instructor data are due to a low (n = 10) survey population. MLLI questionable values in the affective and cognitive/affective domain may relate to overall low values in the affective domain. However, the alpha values are still at or above the lowest value determined by Galloway and Bretz (2015a).

Since the IRT was developed for this study, further tool validation was conducted. Results are described in the next section.

Further Inquiry Rubric Tool Validation

Triangulation between the Fractional Inquiry Score, MLLI results, and qualitative results were also used to validate the data collected by the IRT. Both Fractional and Whole Number scores were calculated for IRT. The Fractional Inquiry Score was calculated using equation (2). The Whole Number value was calculated by taking the percentages for each question and assigning a “provided” to any value greater than 50% and a “not-provided” for 50% or below. The inquiry level was then calculated based on Figure 7 in Chapter 2. Originally, the Fractional Inquiry Score was to be compared to the Whole Number value, but many of the Whole Number calculations gave an error. For example, Inquiry Level 0.5 (Structured Inquiry) is when the student is not told how to communicate their results (Question #5), and there isn't an expected conclusion (Question #6). If the student indicated a less than 50% for the unknown (Question #6) but a greater than 50% for the communication of the results (Question #5), there would be an error in determining the Whole Number value. Table 14 shows the Whole Number scores for the student and instructor IRT surveys and the number of data sets that gave errors.

Table 14

Whole Number Scores for the IRT

Scale	Level 0: Validation	Level 0.5: Structured	Level 1: Guided	Level 2: Open	Level 3: Full	Error
Instructor	4	0	0	0	0	6
Student	25	3	12	0	0	29

The different types of errors were reviewed, and a set of error codes was determined. Seven different error types were defined. These error types and their count are shown in Table 15. The question or questions that caused the error are also listed.

Table 15

Error Types and Counts for Whole Number Inquiry Rubric Score

Error Type	Description	Instructor Count	Student Count
Error Type A	Question #6 (Conclusions) caused the error.	3	10
Error Type B	Questions #2 (Theory/Background) and Question #6 (Conclusions) caused the error.	0	5
Error Type C	Question #5 (Results Communication) caused the error.	0	8
Error Type D	Questions #1 (Problem/Question) and Question #2 (Theory/Background) caused the error.	1	5
Error Type E	Question #3 (Procedure/Design) caused the error.	0	1
Error Type F	Question #4 (Results Analysis) caused the error.	0	1
Error Type X	Multiple questions caused the error.	2	5

With 42% of the student results giving errors, the Whole Number Inquiry Score will not be used for further calculation. Attempts to remedy the errors and applications of the findings will be discussed in Chapter 5.

Further validation was performed via triangulation. In the first attempts to triangulate data, Pearson correlation analysis was conducted between the Fractional Inquiry Score and MLLI Questions #3, #4, #7, #22, and #31. These questions were selected for comparison as they related most closely to inquiry. Each question was prefaced with 'While performing chemistry laboratory experiments in an online environment I…:

3: Made decisions about what data to collect.

4: Felt unsure about the purpose of the procedures.

7: Learned critical thinking skills.

22: Interpreted my data beyond only doing calculations.

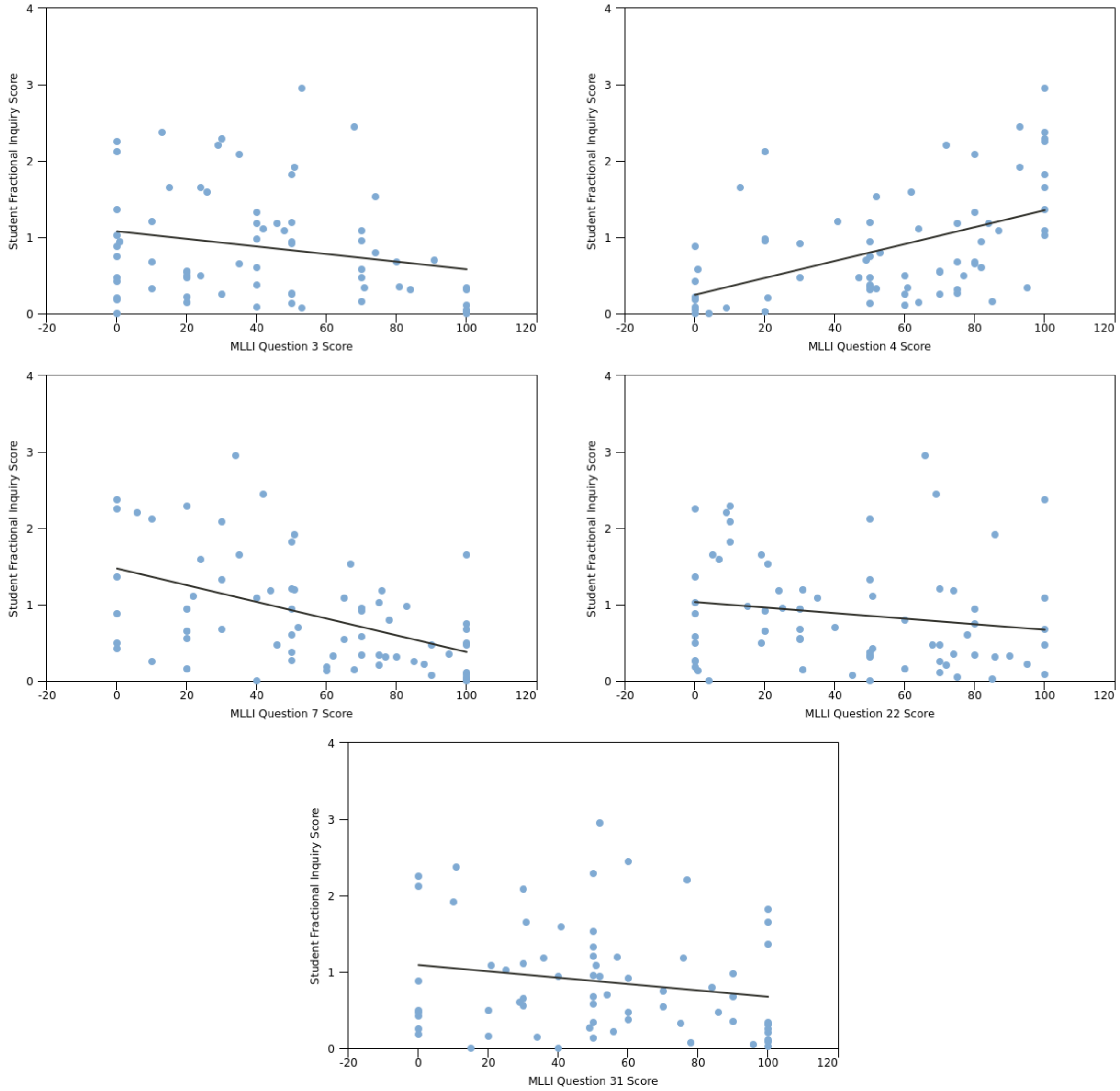
31: Learned problem-solving skills.

A Pearson correlation analysis was conducted between all five questions and the Fractional Inquiry Score per student. Cohen's standard evaluated how strong the relationship was, in which coefficients between 0.10 and 0.29 represent a small effect size, coefficients between 0.30 and 0.49 represent a moderate effect size, and coefficients above 0.50 indicate a large effect size (Cohen, 1988).

To complete a Pearson correlation, the data for variables must be linear (Conover & Iman, 1981). This assumption is violated if curvature exists among the points on a scatter plot. Figure 8 shows the scatterplots for the Student Fractional Inquiry Score as a function of each MLLI question score. None of the charts show a curve that would violate the rule set by Conover and Iman (1981).

Figure 8

Scatterplots with the Regression Line for the Student Fractional Inquiry Score and MLLI Questions #3, #4, #7, #22, and #31



The result of the correlation was based on an alpha value of 0.05. No significant correlation was present for MLLI Questions #3, #22, and #31. For MLLI Question #7, there was a significant negative correlation compared to the Fractional Inquiry Score with a correlation of -0.48, indicating a moderate effect size ($p < 0.001$). This suggests that as the student acquired critical thinking skills, their perceived level of inquiry decreased. This is counterintuitive and will be discussed further in Chapter 5. For MLLI Question #4, there was a significant positive correlation between the two variables, with a correlation of 0.50, indicating a moderate effect size (p < 0.001). This suggests that as students felt unsure about their work, their perceived level of inquiry increased. Table 16 summarizes the Pearson correlation tests.

Table 16

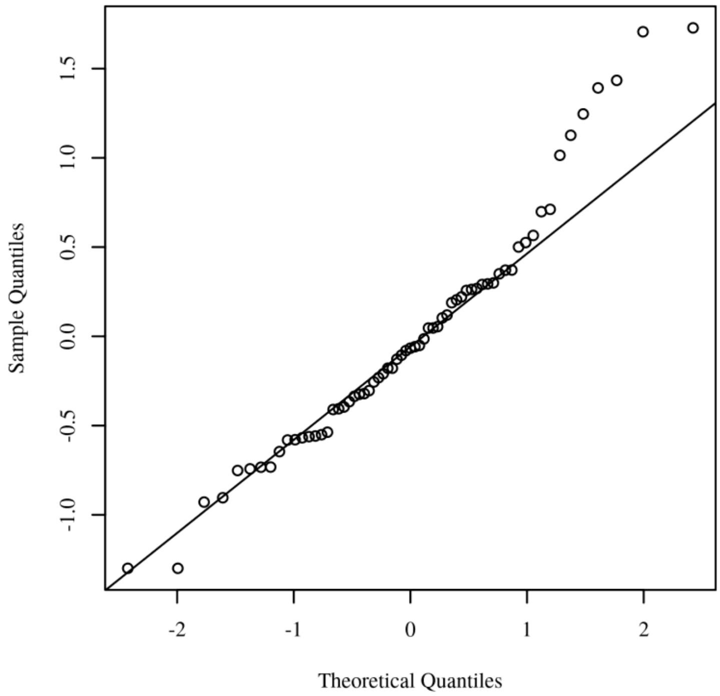
Pearson Correlation Results Comparing Student Fractional Inquiry Score to MLLI Questions #3, #4, #7, #22 and #31

Combination	*r*	95.00% CI	*n*	*p*
Student Fractional Inquiry Score – MLLI Question #3	-0.21	[-0.43, -0.02]	69	0.076
Student Fractional Inquiry Score – MLLI Question #4	0.50	[0.29, 0.66]	69	< 0.001
Student Fractional Inquiry Score – MLLI Question #7	-0.48	[-0.64, -0.28]	69	< 0.001
Student Fractional Inquiry Score – MLLI Question #22	0.17	[-0.39, 0.07]	69	0.172
Student Fractional Inquiry Score – MLLI Question #31	-0.19	[0.41, 0.05]	69	0.124

Further triangulation was attempted with comparisons to the quantitative data. Each student was coded as a “Yes” or “No” when indicating the different types of assignments – Hands-On, Videos, Data Computation, Worksheets, and Virtual Experiments. The intended ANOVA requires an assumption of normality. For the ANOVA testing, the assumption of normality was assessed by plotting the quantiles of the model residuals amongst the quantiles of a Chi-square distribution. This is known as a Q-Q scatterplot (DeCarlo, 1997). For the assumption of normality to be met, the quantiles of the residuals must not strongly deviate from the theoretical quantiles. The Q-Q plot is shown as Figure 9. Unfortunately, substantial deviations at the higher quantiles indicate unreliable parameter estimates. In terms of the triangulation for validity, comparisons cannot be drawn.

Figure 9

Q-Q Scatterplot for Normality of the Residuals for the Regression Model

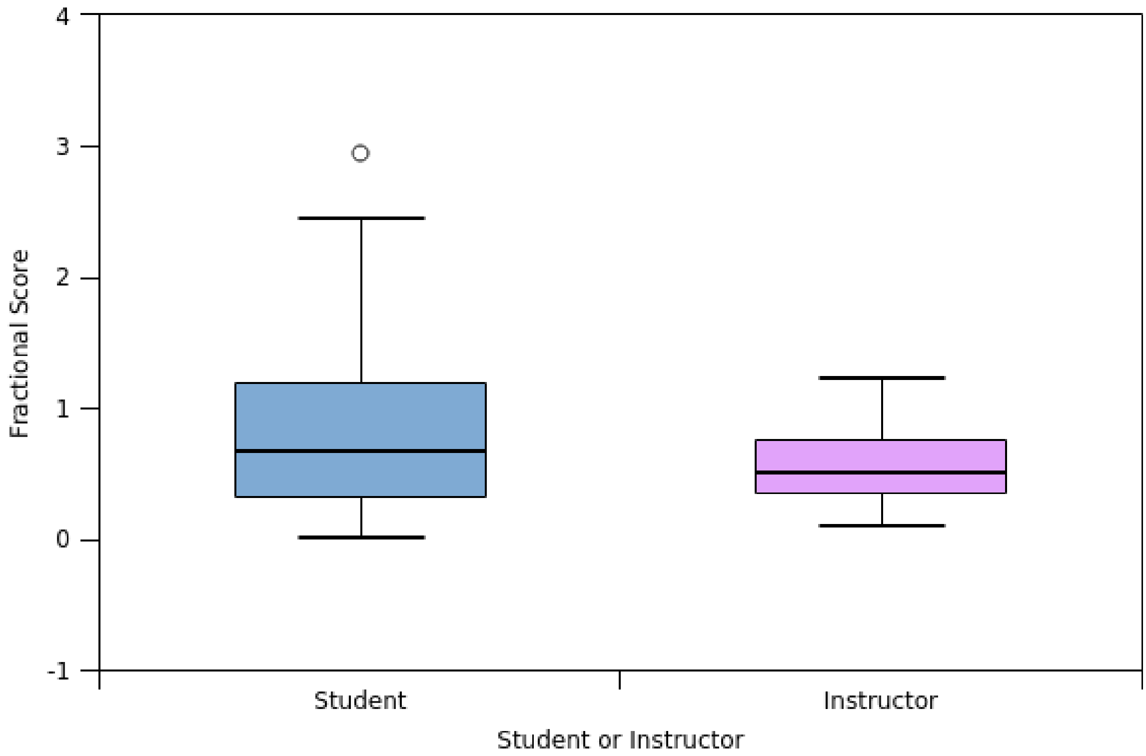


The final test for the validity of the Inquiry Tool was to compare the results of the Fractional Inquiry Score between instructors and students. Initially, a *t*-test was to be performed between the data sets, but given the lack of normality appearing in Figure 9 and the small sample size of the instructor scores, a two-tailed Wilcoxon signed-rank test was performed. The two-tailed Wilcoxon signed-rank test is a non-parametric alternative to the paired samples t-test and does not share its distributional assumptions (Conover & Iman, 1981).

The results indicated that the difference between the two samples' means was insignificant based on an alpha value of 0.05, $V = 33.00$, $z = -0.56$, $p = 0.575$. This indicates that the difference between Student Fractional Inquiry Scores and instructor Fractional Inquiry Scores can be explained by random variation. Figure 10 shows a box plot with error bars of the Student Fractional Inquiry Score mean and the Instructor Fractional Inquiry Score mean.

Figure 10

Profile Plot of Student Fractional Inquiry Score and Instructor Fractional Inquiry Score Means



The IRT has issues in terms of validity. Whole Number values were determined to be unusable due to the levels of errors. Quantitative tests to validate via triangulation failed due to a lack of normality. MLLI Questions #3, #22, and #31 did not correlate to Student Fractional Inquiry Scores. MLLI Questions #4 and #7 showed correlation via Pearson tests, but the results did not reflect the purpose of the IRT. Students indicated that they learned more critical thinking skills at lower levels of inquiry and were more unsure of their data the higher the levels of inquiry.

With all the negatives against the IRT, it still provides valuable information for this study. Cronbach's alpha for the survey's student IRT portion had a relatively high value, indicating good internal consistency. Instructor reported Fractional Inquiry Scores were not different than those that students reported, indicating that both parties perceived the same experience based on the questions. Because of these positives, the Fractional Inquiry Score will still be used for hypothesis analysis. In addition, in Chapter 5, issues with the IRT will be further discussed, along with possible solutions.

Inquiry Rubric Tool Results

The summary of the instructor results of the IRT based on question and Instructor Rubric Score are shown in Table 17. Observations for IRT question #1 (Problem/Question) had an average of 86.30 (*SD* = 25.28), IRT Question #2 (Theory/Background) had an average of 88.40 (*SD* = 16.68), IRT Question #3 (Procedures/Design) had an average of 92.10 (*SD* = 10.20), IRT Question #4 (Result Analysis) had an average of 68.30 (*SD* = 21.39), IRT Question #5 (Results Communication) had an average of 93.00 (*SD* = 16.36) and IRT Question #6 (Conclusions) had an average of 47.40 (*SD* = 24.50). Regarding the Fractional Score, the Instructor Fractional Score had an average of 0.57 (*SD* = 0.37). Skewness and kurtosis are shown in addition to averages. When skewness is greater than 2 in absolute value, the variable is asymmetrical about its mean. When the kurtosis is greater than or equal to 3, the variable's distribution is markedly different from a normal distribution and produces outliers (Westfall & Henning, 2013).

Table 17

Summary Statistics Table for IRT Instructor Results

Variable	*M*	*SD*	*n*	SEM	Min	Max	Skewness	Kurtosis
IRT Question #1	86.30	25.28	10	7.99	20.00	100.00	-2.02	2.91
IRT Question #2	88.40	16.68	10	5.28	53.00	100.00	-1.05	-0.16
IRT Question #3	92.10	10.20	10	3.23	80.00	100.00	-0.41	-1.83
IRT Question #4	68.30	21.39	10	6.76	29.00	91.00	-0.57	-1.05
IRT Question #5	93.00	16.36	10	5.17	50.00	100.00	-2.11	2.97
IRT Question #6	47.40	24.50	10	7.75	18.00	90.00	0.35	-1.16
Instructor Fractional Inquiry Score	0.57	0.37	10	0.12	0.09	1.23	0.54	-0.82

Student scores for the IRT portion of the survey were also tabulated. Observations for IRT Question #1 (Problem/Question) had an average of 79.29 (*SD* = 27.95), IRT Question #2

(Theory/Background) had an average of 72.45 (*SD* = 30.34), IRT Question #3 (Procedures/Design) had an average of 76.59 (*SD* = 32.00), IRT Question #4 (Result Analysis) had an average of 64.43 (*SD* = 29.19), IRT Question #5 (Results Communication) had an average of 73.20 (*SD* = 30.07) and IRT Question #6 (Conclusions) had an average of 52.01 (*SD* = 32.10). Regarding the Fractional Score, the average Student Fractional Inquiry Score was 0.87 (*SD* = 0.72). Table 18 shows a summary of statistics, including skewness and kurtosis.

Table 18

Summary Statistics Table for IRT Student Results

Variable	*M*	*SD*	*n*	SEM	Min	Max	Skewness	Kurtosis
IRT Question #1	79.29	27.95	69	3.36	0.00	100.00	-1.45	1.07
IRT Question #2	72.45	30.34	69	3.65	0.00	100.00	-0.83	-0.73
IRT Question #3	76.59	32.00	69	3.85	0.00	100.00	-1.31	0.31
IRT Question #4	64.43	28.19	69	3.39	0.00	100.00	-0.62	-0.45
IRT Question #5	73.20	30.07	69	3.62	0.00	100.00	-0.92	-0.27
IRT Question #6	52.01	32.10	69	3.86	0.00	100.00	-0.005	-1.30
Student Fractional Inquiry Score	0.87	0.72	69	0.09	0.00	2.95	0.93	0.02

The student portion of the Inquiry Rubric Survey was used to evaluate Research Question #1 and corresponding hypothesis 1:

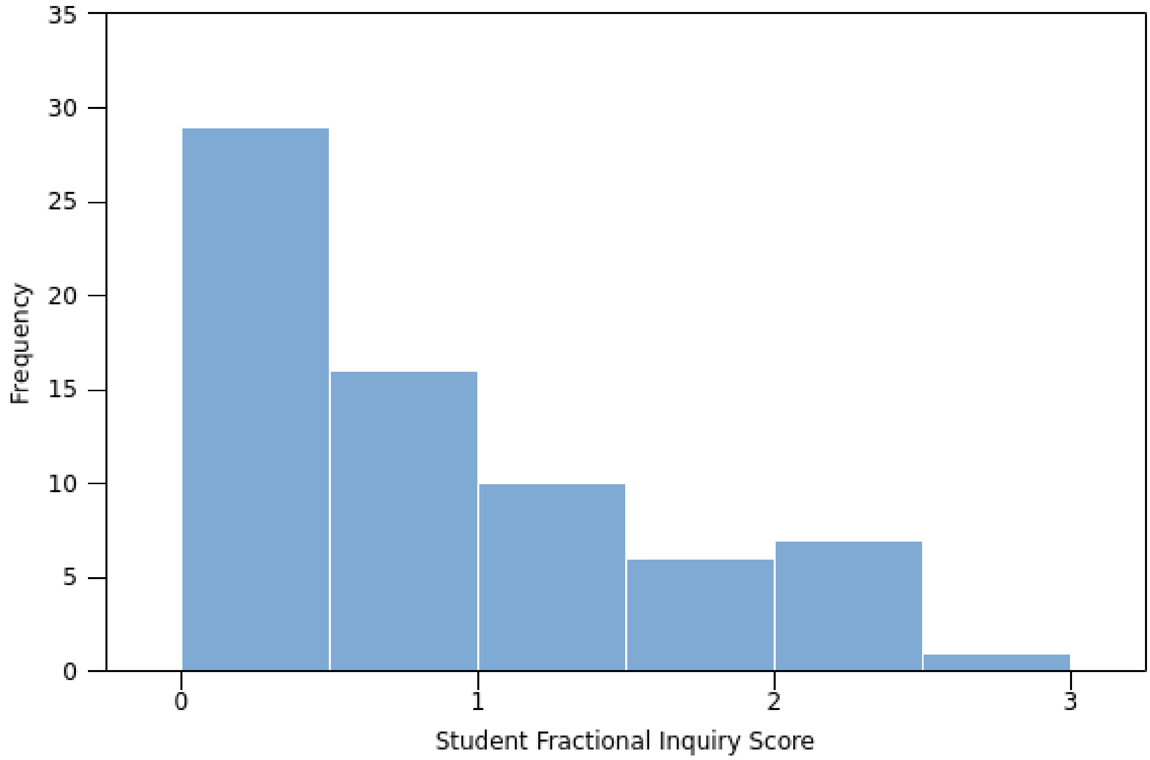
- RQ1: In terms of inquiry-based learning, what was the laboratory experience for students at El Camino College during ERT?
- H_{o1}: There is no difference between the level of inquiry students experienced during ERT at El Camino College.
- H_{a1}: There is a difference between the level of inquiry students experienced during ERT at El Camino College.

The Shapiro-Wilk test was conducted to determine whether the distribution of Student Fractional Inquiry Scores significantly differed from a normal distribution. If the distribution was normal, students experienced different levels of inquiry. Based on an alpha of 0.05, the

Student Fraction Inquiry Score (*W* = 0.90, $p < 0.01$) is significantly different from a normal distribution. Results indicate that the null hypothesis is held true. The Q-Q plot above, shown as Figure 9, supports this lack of normality. An additional histogram of Student Fractional Inquiry scores is shown in Figure 11 below, collaborating this evidence.

Figure 11

Histogram of Student Fractional Inquiry Score in Support of Non-Normality



Meaningful Learning in Laboratory Instrument Results

The raw summary for the MLLI is shown in Tables 19, 20, and 21, broken up by question category (cognitive, affective, and cognitive/affective. Each question is prefaced with, “While performing chemistry laboratory experiments in an online environment, I…” Questions are shown as raw values—negative questions have not been reversed. Skewness and kurtosis are also shown.

Table 19

Summary Statistics Table for Cognitive Questions of the MLLI Portion of the Student Survey

Variable	*M*	*SD*	*n*	SEM	Min	Max	Skewness	Kurtosis
Question #3 Made decisions about what data to collect	41.57	31.09	69	3.74	0.00	100.00	0.33	-0.89
Question #5 Experienced moments of insight	49.83	33.79	69	4.07	0.00	100.00	0.04	-1.27
Question #6 Was confused about how the instruments/programs work	59.23	31.30	69	3.77	0.00	100.00	-0.40	-0.92
Question #7 Learned critical thinking skills	54.94	31.71	69	3.82	0.00	100.00	-0.19	-1.06
Question #10 Considered if my data makes sense	69.01	31.32	69	3.77	0.00	100.00	-0.93	-0.26
Question #11 Thought about what the molecules are doing	49.64	32.90	69	3.96	0.00	100.00	-0.04	-1.23
Question #15 Thought the procedures simple to do	39.06	27.34	69	3.29	0.00	100.00	0.32	-0.71
Question #16 Was confused about underlying concepts	65.36	26.11	69	3.14	0.00	100.00	-0.69	-0.06
Question #17 “got stuck” but kept trying	76.49	26.74	69	3.22	0.00	100.00	-1.34	1.11
Question #19 Thought about chemistry I already know	63.43	31.54	69	3.80	0.00	100.00	-0.65	-0.67
Question #22 Interpreted my data beyond only doing calculations	44.65	32.90	69	3.96	0.00	100.00	0.12	-1.30
Question #24 Focused on procedures, not concepts.	63.49	29.64	69	3.57	0.00	100.00	-0.55	-0.65
Question #25 Used my observations to understand the behavior of atoms and molecules	49.12	28.15	69	3.39	0.00	100.00	-0.07	-0.87
Question #26 Made mistakes and tried again	77.57	25.41	69	3.06	0.00	100.00	-1.32	1.39
Question #29 Was confused about what my data meant	69.16	28.07	69	3.38	0.00	100.00	-0.84	-0.05
Question #31 Learned problem-solving skills.	52.70	32.37	69	3.90	0.00	100.00	-0.02	-1.04

Table 20

Summary Statistics Table for Affective Questions of the MLLI Portion of the Student Survey

Variable	*M*	*SD*	*n*	SEM	Min	Max	Skewness	Kurtosis
Question #2 Worried about finishing on time	67.55	36.10	69	4.35	0.00	100.00	-0.66	-1.15
Question #8 Was excited to do chemistry	44.84	34.62	69	4.17	0.00	100.00	0.28	-1.30
Question #9 Was nervous about making mistakes	70.41	33.23	69	4.00	0.00	100.00	-0.93	-0.38
Question #13 Developed confidence in the laboratory	25.65	34.52	69	4.16	0.00	100.00	1.20	-0.20
Question #18 Was nervous about employing the program or performing experiments at home when applicable	50.83	33.04	69	3.98	0.00	100.00	-0.08	-1.16
Question #21 Was frustrated	78.43	27.03	69	3.25	0.00	100.00	-1.37	1.00
Question #28 Felt intimidated	70.23	33.30	69	4.01	0.00	100.00	-0.84	-0.67
Question #30 Was confident when using equipment/programs	36.55	29.99	69	3.61	0.00	100.00	0.49	-0.75

Table 21

Summary Statistics Table for Cognitive/Affective Questions of the MLLI Portion of the Student Survey

Variable	*M*	*SD*	*n*	SEM	Min	Max	Skewness	Kurtosis
Question #1 Learned chemistry that will be useful in my life	44.62	28.06	69	3.38	0.00	100.00	0.26	-0.70
Question #4 Felt unsure about the purpose of procedures	56.42	32.33	69	3.89	0.00	100.00	-0.41	-0.96
Question #12 Felt disorganized	59.14	36.51	69	4.40	0.00	100.00	-0.32	-1.39
Question #14 Worried about getting good data	57.41	36.09	69	4.35	0.00	100.00	-0.37	-1.29
Question #20 Worried about the quality of my data	62.64	35.15	69	4.23	0.00	100.00	-0.62	-1.00
Question #27 Was intrigued by the instruments/programs used for laboratory assignments	57.64	32.66	69	3.93	0.00	100.00	-0.36	-1.05

Questions designated as ‘hindering’ meaningful learning (#2, #4, #6, #9, #12, #14, #15, #16, #18, #20, #21, #24, #28, #29) were reversed as indicated in Chapter 3. Overall averages between each question group were then calculated. For cognitive-based questions, the average was 44.75 (*SD* = 20.40). The average affective score was 33.70 (*SD* = 18.64). The cognitive/affective average score was 52.04 (*SD* = 12.71). In addition to these values, though not done in the literature, an overall meaningful learning score was calculated by averaging all the questions. This value was 45.96 (*SD* = 12.58). Table 22 shows a summary of these values.

Table 22

Summary of Descriptives for the Average Cognitive, Affective and Cognitive/Affective Scores From Student Surveys at El Camino

Variable	*M*	*SD*	*n*	SEM	Min	Max	Skewness	Kurtosis
Cognitive	52.04	12.71	69	1.53	30.25	82.19	0.28	-0.61
Affective	33.70	18.64	69	2.24	0.00	83.00	0.55	-0.25
Cognitive/Affective	44.75	20.40	69	2.46	11.00	98.50	0.52	-0.25
MLLI Overall	45.69	12.58	69	1.51	21.60	77.60	0.28	-0.30

MLLI Results Compared to the Literature

The MLLI portion of the survey related two research questions and two hypotheses. The first pairing concerned literature values:

- RQ2: Is the overall level of meaningful learning experienced by students at El Camino College during ERT similar to published literature values?
- H_{o2}: There is no statistical difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values.
- H_{b1}: There is a significant difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values.

Three different publications were used to compare values from this study to the literature. The first is the Galloway and Bretz (2015a) paper regarding creating the MLLI instrument. Post-class survey values for the reported general and organic chemistry classes were used for comparison. Four data sets from Enneking et al. (2019) were also used. These were selected as they had both hybrid laboratories and traditional in-person laboratories. The final data set used was by Jones et al. (2021), which detailed results from an online course during ERT, though the author did not report cognitive/affective scores.

A series of two-tailed paired samples *t*-tests were conducted to examine whether the means between the individual scores from this study were significantly different from those in the literature. The normality of this study's values was conducted via a Shapiro-Wilk test (Razali & Wah, 2011). Results were determined based on an alpha value of 0.05. Both the cognitive values ($W = 0.98$, $p = 0.212$) and affective values ($W = 0.97$, $p = 0.054$) had distributions that did not vary significantly from normality. The cognitive/affective values ($W = 0.96$, $p = 0.033$) had a distribution which significantly differed from normality. Since the author of this work does not have access to the raw data generated by the compared literature, a Wilcoxon Signed-Rank Test could not be conducted. Cognitive/affective values will still be compared using a *t*-test, but the violation of normality is noted.

In the following, each set of data is discussed. When the *p*-value for a given *t*-test was less than the alpha of 0.05, the null hypothesis (there is no difference in the literature to those reported in this work) was rejected. Each table indicates whether the null was rejected.

The results for the individual *t*-tests with Galloway and Bretz's (2015a) work are shown in Table 23. When comparing in-person classes from the initial run of MLLI, cognitive ($t = 3.51$, $p < 0.01$) and affective ($t = 7.05$, $p < 0.01$) scores compared to general chemistry sources were significantly lower than those reported by Galloway and Bretz (2015a). When comparing cognitive/affective questions, there was no significant difference ($t = 0.0249$, $p = 0.980$) between the two values. When comparing in-person organic classes to this study, only the affective was significantly lower ($t = 4.38$, $p < 0.01$). Both the cognitive (*t* = 1.92, *p* = 0.0559) and cognitive/affective (*t* = -1.60, *p* = 0.111) were not significantly different.

Table 23

Galloway and Bretz (2015a) Comparisons Between Cognitive, Affective and Cognitive/Affective Scores for General Chemistry and Organic Chemistry In-Person Classes

Class	*n*	Question Group	Score	*SD*	*t*	*p*	H_{o2} Rejected (Y/N)
In-Person General	436	Cog	57.9	12.9	3.51	4.83e-4	Y
	436	Aff	50.3	18.1	7.05	5.94e-12	Y
	436	Cog/Aff	44.8	17.1	0.0249	0.980	N
In Person Organic	178	Cog	55.8	14.2	1.92	0.0559	N
	178	Aff	44.6	14.6	4.38	1.74e-5	Y
	178	Cog/Aff	40.9	15.5	-1.60	0.111	N

Results comparing to Enneking et al. (2019) are shown in Tables 24 and 25. Results were broken down into two different tables by grouping in-person, traditional general chemistry classes and those that were hybrid. Enneking et al. (2019) reported two different semesters, so both are used for comparison. When comparing In-Person A, cognitive (*t* = 7.20, *p* < 0.001), affective (*t* = 13.1, *p* < 0.001) and cognitive/affective (*t* = 5.59, *p* < 0.001) scores in this study were considerably lower than those reported by Enneking et al. (2019). Similar results were seen for the second in-person group reported by Enneking et al. (2019), with cognitive (*t* = 10.3, *p* < 0.001), affective (*t* = 13.8, *p* < 0.001) and cognitive/affective (*t* = 7.92, *p* < 0.001) scores were significantly lower in this study than Enneking et al. (2019) reported. When comparing hybrid courses reported by Enneking et al. (2019) to this work, both sets of courses had significantly lower cognitive (*t* = 5.10, *p* < 0.001/*t* = 3.31, *p* < 0.001), affective (*t* = 7.72, *p* < 0.001/*t* = 6.45, *p* < 0.001) and cognitive/affective (*t* = 3.24, *p* < 0.001/*t* = 4.42, *p* < 0.001) questions. For all cases with Enneking et al's. (2019) work, the null was rejected and significant differences were shown.

Table 24

Enneking et al. (2019) Comparisons Between Cognitive, Affective and Cognitive/Affective Scores for General Chemistry In-Person Classes

Class	*n*	Question Group	Score	*SD*	*t*	*p*	H_{o2} Rejected (Y/N)
In-Person A	365	Cog	64.2	13.8	7.20	2.74e-12	Y
	365	Aff	64.3	17.6	13.1	0	Y
	365	Cog/Aff	57.6	15.6	5.59	5.51e-9	Y
In Person B	581	Cog	65.4	9.9	10.3	0	Y
	581	Aff	56.4	12.1	13.8	0	Y
	581	Cog/Aff	60.2	14.6	7.92	9.99e-15	Y

Table 25

Enneking et al. (2019) Comparisons Between Cognitive, Affective and Cognitive/Affective Scores for General Chemistry Hybrid Classes

Class	*n*	Question Group	Score	*SD*	*t*	*p*	H_{o2} Rejected (Y/N)
Hybrid A	112	Cog	62.5	13.8	5.10	8.52e-7	Y
	112	Aff	59.5	23.6	7.72	8.10e-13	Y
	112	Cog/Aff	54.6	19.5	3.24	1.41e-3	Y
Hybrid B	83	Cog	58.2	10.2	3.31	1.15e-4	Y
	83	Aff	50.9	14.2	6.45	1.43e-9	Y
	83	Cog/Aff	58.3	17.4	4.42	1.89e-6	Y

The final comparison was with an online introductory chemistry course, forced into ERT, reported by Jones et al. (2021), though the authors only reported cognitive and affective scores. Table 26 shows the results when compared to this study. The results in this study were significantly lower for both cognitive (t = 10.1, p < 0.001) and affective (t = 7.64, p < 0.001). Therefore, the null was rejected for both tests.

Table 26

Jones et al. (2021) Comparisons Comparing Cognitive and Affective Scores for a General Chemistry ERT Course

Class	*n*	Question Group	Score	SD	*t*	*p*	H_{o2} Rejected (Y/N)
General Chemistry ERT	123	Cog	66.2	12.1	10.1	0.00	Y
	123	Aff	57.8	14.0	7.64	1.04e-12	Y

From the three literature studies, 14 different two-sample t-tests were conducted. Out of those tests, 11 results rejected the null H_{o2}, and three did not. Those that did not reject the null fell under the cognitive and cognitive/affective domains. Given this information regarding Research Question 2, results showed that affective scores were significantly lower in this study compared to the literature. Cognitive and cognitive/affective questions were mainly lower than those selected from the literature. Overall, this means that the level of meaningful learning was generally lower than that reported in the literature.

MLLI Results Compared to IRT

The second research question regarding results from the MLLI compared values to those determined in the IRT. The paired research question and hypotheses are:

- RQ3: Was there a link between the level of inquiry and the level of meaningful learning experienced by students at El Camino College during ERT?
- H_{o3}: There is no correlation between the level of inquiry reported by students and the overall level of meaningful learning experienced in laboratory exercises by El Camino College students during ERT.
- H_{c1}: There is a positive correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.
- H_{c2}: There is a negative correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.

Pearson R analysis was conducted to assess this research question and the corresponding hypotheses, comparing cognitive, affective, cognitive/affective, and overall MLLI scores to the Fractional Inquiry Score. As with the validation of the IRT, Cohen's standard was used to evaluate the strength of the relationship, with coefficients between 0.10

and 0.29 representing a small effect size, coefficients between 0.30 and 0.49 representing a moderate effect size, and coefficients above 0.50 indicating a large effect size (Cohen, 1988). In addition, the data variables must have some sense of linearity (Conovoer & Iman, 1981). The assumption of linearity is violated if curvature exists among the points on a scatter plot. Figure 12 shows the scatter plots of cognitive, affective, cognitive/affective, and overall meaningful learning scores as a function of the individual Student Fractional Inquiry Score. The assumption is not violated since the graphs do not demonstrate significant curves.

Figure 12

Scatter Plots for Cognitive, Affective, Cognitive/Affective, and Overall Meaningful Learning as a Function of Inquiry Rubric Score

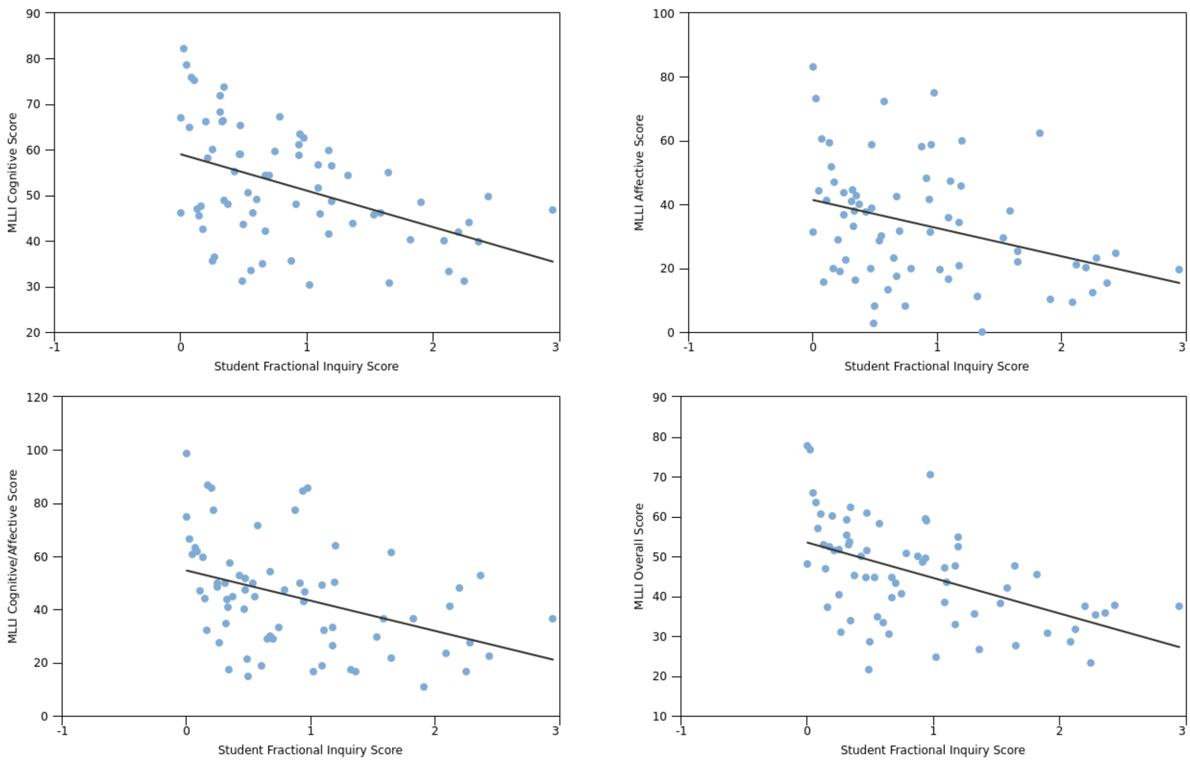


Table 27 shows the results of the Pearson R testing. Results are based on an alpha value of 0.05. A significant negative correlation was observed between the MLLI cognitive score and the Student Fractional Inquiry Score ($p < 0.001$) and a moderate effect size (r = -0.45). This means that as the Fractional Inquiry Score decreases, the MLLI cognitive score increases. When comparing MLLI affective scores to the Fractional Inquiry Score, a significant negative correlation was determined ($p = 0.004$) with a moderate effect size (r = -

0.34). This means that as the Fractional Inquiry Score increases, the MLLI affective score decreases. When comparing the MLLI cognitive/affective score to the Fractional Inquiry Score, it was determined that there was a significant negative correlation ($p < 0.001$) with a moderate size effective ($r = -0.40$). This indicates that the MLLI cognitive/affective score decreases as the Fractional Inquiry Score increases. Finally, when comparing the overall MLLI score to the Fractional Inquiry Score, it was determined there was a significant negative correlation ($p < 0.001$) and large effect size ($r = -0.51$). All tests show a negative correlation between the MLLI component and the Fractional Inquiry Score, meaning that the null (H_{o3}) was rejected and H_{c2} was accepted.

Table 27

Pearson R Correlation Factors Between Cognitive, Affective, Cognitive/Affective and Overall MLLI Scores Compared to the Fractional Inquiry Score

Combination	*r*	95.00% CI	*n*	*p*
Cognitive - Student Fractional Inquiry Score	-0.45	[-0.62, -0.24]	69	< 0.001
Affective - Student Fractional Inquiry Score	-0.34	[-0.53, -0.11]	69	0.004
Cognitive/Affective - Student Fractional Inquiry Score	-0.40	[-0.58, -0.18]	69	< 0.001
Overall MLLI - Student Fractional Inquiry Score	-0.51	[-0.67, -0.31]	69	< 0.001

Research Question 4 and Emergent Results

The last research question looked at the overall experience for students while taking online chemistry courses with a laboratory component at El Camino College. The research question did not have any formal hypotheses associated with it::

- RQ4: What was the phenomenological experience for students in ERT laboratory exercises at El Camino College?

To develop this phenomenological understanding, several different results were considered. One question in the survey asked the student how many semesters they spent online. Several tests were performed using this information. In addition to code counts, students were also annotated as possessing a specific code. For example, if a student was coded for Confusing, they were noted as having this code, regardless of the number of times the individual was coded for it. Finally, several ANOVA tests and independence *t*-tests were performed between the Fractional Inquiry Score, the MLLI values, and codes from the qualitative section. Only results are given in this section. The meaning of these results and how they are essential in answering RQ4 will be discussed in Chapter 5.

Comparison to Semesters Online

After the Informed Consent, the first two questions for students asked whether they had taken any chemistry courses with a laboratory component at El Camino College during ERT. The second asked how many semesters the student had these courses. Table 28 summarizes the number of semesters students indicated they took online classes.

Table 28

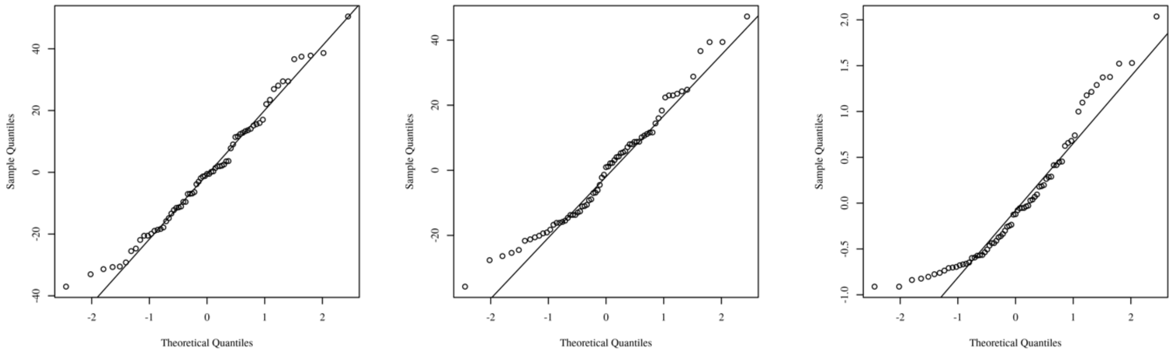
Frequency Table for Number of Semesters Spent Online in Chemistry During ERT

Number of Semesters	*n*	%
1 Semester Online	44	63.77
2 Semesters Online	14	20.29
3 Semesters Online	3	4.35
4 Semesters Online	8	11.59

To determine a relationship between the number of semesters online and the experience students had during their chemistry laboratory assignments, three different ANOVA tests were performed—the MLLI cognitive score, the MLLI affective score, and the Fractional Inquiry Score. ANOVA tests assume normality. Q-Q scatterplots were developed for each of the three tests for normality testing, shown in Figure 13. For the cognitive and affective Q-Q scatterplots, normality may be assumed. The Fractional Inquiry Score Q-Q plot shows deviations at the higher and lower quantiles, similar to the earlier Q-Q plot based on Fractional Inquiry Scores. These abnormalities were noted, and the ANOVA tests were conducted.

Figure 13

Q-Q Plots for Analysis of Variance Test of Cognitive, Affective, and Student Fractional Inquiry Score Compared to Number of Semesters Spent in ERT



The ANOVA was examined based on an alpha value of 0.05. The results were not significant for the cognitive test, $F(3, 65) = 1.02$, $p = 0.391$, indicating no statistically significant differences in the MLLI cognitive scores among the different values for semesters online. The results were not significant for the affective test, $F(3, 65) = 0.92$, $p = 0.436$, indicating the differences in the MLLI affective scores were similar across semester totals online. Finally, the Fractional Inquiry Score was tested. The results were not significant, $F(3, 65) = 0.43$, $p = 0.732$, meaning that the levels in the Fractional Inquiry Scores were not different across different semesters totals online. These tests indicate that none of the scores were related to the number of semesters online. A summary of these results appears in Table 29.

Table 29

Analysis of Variance Table for Cognitive Scores, Affective Scores, and Fractional Inquiry Scores by Total Semesters Spent Online in Chemistry

Term	*SS*	*df*	*F*	*p*	*Np2*
Cognitive	492.24	3	1.02	0.391	0.04
Cognitive Residuals	10486.11	65			
Affective	963.62	3	0.92	0.436	0.04
Affective Residuals	22669.07	65			
Fractional Inquiry Score	0.69	3	0.43	0.732	0.02

Term	*SS*	*df*	*F*	*p*	*Np2*
Fractional Inquiry Score Residuals	34.58	65			

Additional Coding Metrics

Further coding analysis elucidated students' experience during online chemistry laboratory classes more fully. Instead of simply counting a code, a student was given an indicator of "Yes" or "No" if they had a particular code. For example, if a student was coded three times for "Confusing," they still would only be indicated as "Yes" for further exploration, regardless of the number of times the student was coded for "Confusing." These findings can now be given as the number of students demonstrating a code.

Table 30 shows the results for individual codes per student. A student was marked as part of the n value for "Yes" and "No" if coded for a particular code in any of the five qualitative questions. The "Watching Instructor" and "Videos" codes were combined. The percentage in the table will total lower than 100%, as four students did not respond to the quantitative portion of the survey. This data was attached to each individual student so that responses from the IRT and MLLI parts of the study could be compared via ANOVA and *t*-tests.

Table 30

Frequency Table for Coding on a Per Student Basis

Code	Students Coded (Yes)	%	Students Not Coded (No)	%
Flexible	7	10.14	58	84.06
Easy	9	13.04	56	81.16
Relating/Relevance Positive	10	14.49	55	79.71
Relating/Relevance Negative	25	36.23	40	57.97
Confusing	28	40.58	37	53.62
Difficult	14	20.29	51	73.91
Information Not Important	11	15.94	54	78.26
Time Issues	7	10.14	58	84.06
Enjoyed Visuals	9	13.04	56	81.16
Ease of Use	12	17.39	53	76.81
Lack of Data Understanding	5	7.25	60	86.96
Low Quality Materials	16	23.19	49	71.01
No Good Experience	19	27.54	46	66.67
Positive Instructor Experience	2	2.90	63	91.90
Negative Instructor Experience	16	23.19	49	71.01
Positive Group Experience	14	20.29	51	73.91
Negative Group Experience	5	7.25	60	86.96
Positive Experiences	18	26.09	47	68.12
Negative Experiences	35	50.72	30	43.48
Desire for Hands-On Experience	24	34.78	41	59.42
COVID-19 Understanding	7	10.14	58	84.06
Videos + Watching Instructor	34	49.28	31	44.93
Data Computation	10	14.49	55	79.71
Worksheets	38	55.07	27	39.13
Interactive Labs	19	27.54	46	66.67
Actual Experimentation	4	5.80	61	88.41
No Input	52	75.36	13	18.84
Some Input	6	8.70	59	85.51
Lots of Input	3	4.35	62	89.86

Another variance in coding to fully understand the student experience was breaking several codes into two groups—positive and negative. Positive codes include Positive Experience, Positive Instructor Experience, Positive Group Experience, Flexible, Easy, Relating/Relevance Positive, Enjoyed Visuals, and Ease of Use. Negative codes included Negative Experience, Instructor Issues, Negative Group Experience, Relating/Relevance Negative, Confusing, Difficult, Information Not Important, Not Understanding Data, Low

Quality Materials, Time Issues, and No Good Experience. The total number of times a student was coded for a positive or negative experience was determined per student. Table 31 describes the overall results on a per-student basis. Results indicate a much higher number of negative codes per student.

Table 31

Summary Statistics Table for Positive and Negative Codes on a Per Student Basis

Variable	*M*	*SD*	*n*	SEM	Min	Max	Skewness	Kurtosis
Positive Codes Per Student	1.16	1.07	65	0.13	0.00	4.00	0.35	-0.33
Negative Codes Per Student	2.78	1.42	65	0.18	0.00	7	0.49	0.26

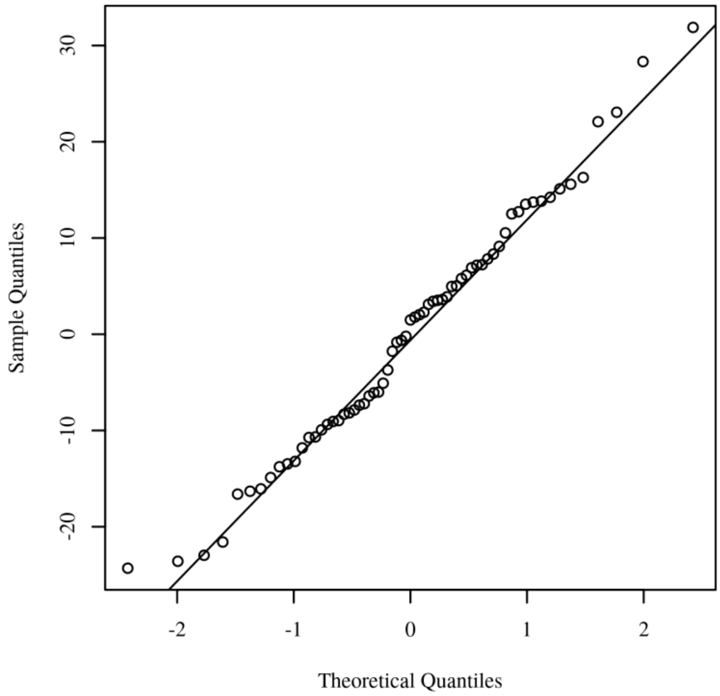
Coding and Quantitative Comparisons

With the deeper level of coding analysis performed, several tests were conducted comparing the results from the IRT and MLLI portions of the survey. This was done to help address Research Question 4 to determine if the types of laboratory replacement exercises students indicated in the open survey section impacted their cognitive or affective domains or affected their perceived level of inquiry.

The first series of tests conducted were several ANOVA evaluations. The first comparisons were performed between cognitive, affective, meaningful learning, and Student Fractional Inquiry Scores compared to the different laboratory assignments—videos, data computations, virtual labs, hands-on exercises, and worksheets. Q-Q plots were calculated for each set. These plots have been posted as previous figures (Figure 13) except for meaningful learning. Student Fractional Inquiry Score was noted as deviating from normality at the extremes. The Q-Q plot for meaningful learning is shown as Figure 14.

Figure 14

Q-Q Plot Testing for Normality of the Meaningful Learning Variable



ANOVA tests were performed as each of the individual MLLI, and IRT variables acted as the dependent variable and indicated whether or not a student had a particular type of laboratory assignment as the independent. The alpha value for these tests was 0.05. Results are shown in Table 32. Regarding cognitive scores from the MLLI portion, there was no difference between the laboratory assignment groups' scores. For affective scores from the MLLI portion, there was no difference between the scores amongst any of the laboratory assignment groups.

Similarly, the overall meaningful learning score showed no significant difference among the different laboratory activities. For the Student Fractional Inquiry Score, the only laboratory assignment that showed substantial differences was virtual assignments. Students who had virtual laboratory assignments indicated lower Student Fractional Inquiry Scores than those who did not have virtual laboratory assignments.

Table 32

Analysis of Variance for Cognitive, Affective, Meaningful Learning, and Student Fractional Inquiry Score Compared to Laboratory Assignments

Term	*SS*	*df*	*F*	*p*	*Np2*
Cognitive – Hands-On	352.80	1	2.15	0.148	0.04
Cognitive - Videos	2.57	1	0.02	0.901	0.00
Cognitive – Data Computation	108.32	1	0.66	0.420	0.001
Cognitive – Worksheets	225.30	1	1.37	0.246	0.02
Cognitive – Virtual Labs	0.09	1	0.00	0.981	0.00
Affective – Hands On	180.82	1	0.50	0.482	0.01
Affective - Videos	510.03	1	1.41	0.239	0.02
Affective – Data Computation	12.57	1	0.03	0.853	0.00
Affective – Worksheets	2.79	1	0.01	0.930	0.00
Affective – Virtual Labs	362.61	1	1.01	0.320	0.02
Meaningful Learning – Hands On	170.94	1	0.99	0.325	0.02
Meaningful Learning - Videos	51.45	1	0.030	0.588	0.01
Meaningful Learning – Data Computation	27.89	1	0.16	0.690	0.00
Meaningful Learning – Worksheets	8.60	1	0.05	0.824	0.00
Meaningful Learning – Virtual Labs	36.51	1	0.21	0.648	0.00
SFRS – Hands On	1.37	1	2.90	0.94	0.05
SFRS - Videos	1.69	1	3.60	0.063	0.06
SFRS – Data Computation	1.81	1	3.85	0.055	0.06
SFRS – Worksheets	0.05	1	0.11	0.743	0.00
SFRS – Virtual Labs	3.82	1	8.10	0.006	0.12

Additional ANOVA analysis was conducted using values from both MLLI and IRT but grouped by how many times a student was coded with a positive or negative code. Alpha values for each test were 0.05. Table 33 shows the results of the analysis of variance. There were no differences between the cognitive values for the different codes or the Student Fractional Inquiry Score. Both the affective (p = 0.019) and the overall meaningful learning score (p = 0.045) regarding the number of negative codes were significantly different. This indicates that as negative codes increased, the affective score decreased. Box plots for the affective scores are shown in Figure 15.

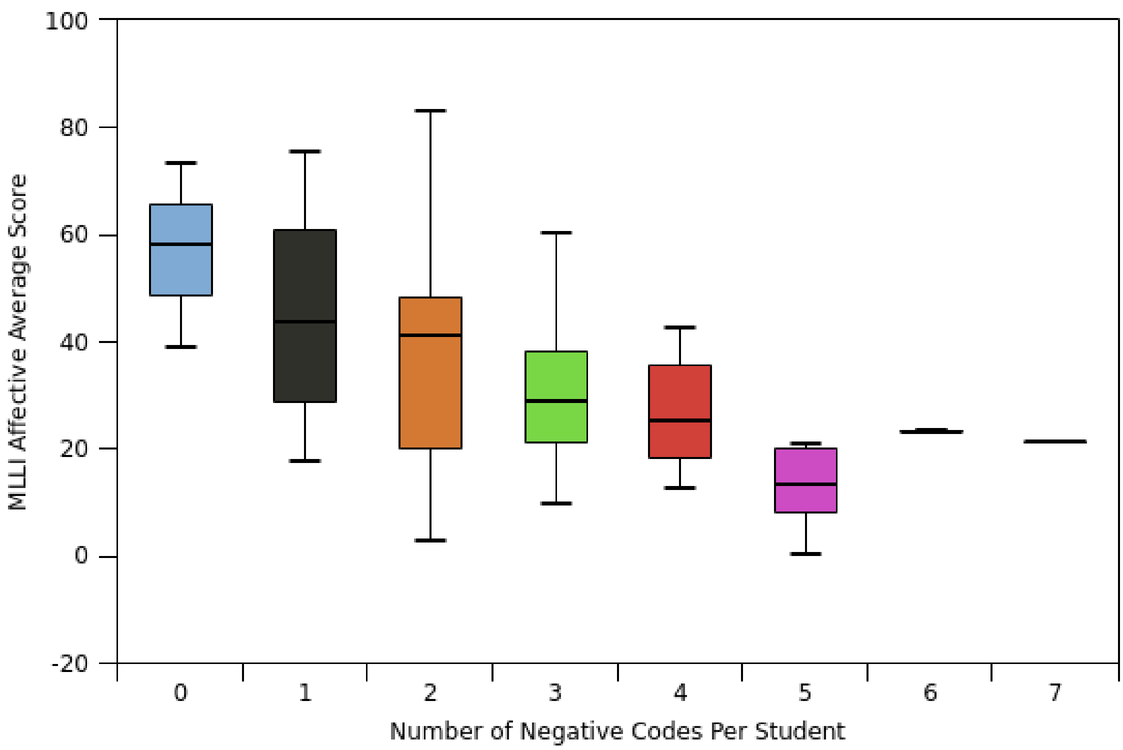
Table 33

Analysis of Variance for Cognitive, Affective, Meaningful Learning, and Student Fractional Inquiry Score Compared to Laboratory Assignments

Term	*SS*	*df*	*F*	*p*	*Np2*
Cognitive – Positive Codes	603.92	4	0.97	0.431	0.07
Cognitive – Negative Codes	1347.51	7	1.24	0.299	0.14
Affective – Positive Codes	629.19	4	0.53	0.717	0.04
Affective – Negative Codes	5623.89	7	2.68	0.019	0.26
Meaningful Learning – Positive Codes	319.11	4	0.57	0.687	0.04
Meaningful Learning – Negative Codes	2204.28	7	2.24	0.045	0.23
SFRS – Positive Codes	2.66	4	1.31	0.277	0.09
SFRS – Negative Codes	5.51	7	1.55	0.170	0.17

Figure 15

Box Plots Demonstrating Differences in Affective Scores Per Student Regarding the Number of Negative Codes



Given that there was no relationship between the number of negative or positive codes with cognitive effects, a Pearson correlation analysis was conducted to see if there was a relationship between a student's cognitive score and their affective score. Cohen's standard was used as described earlier in this work. The correlation result was examined based on an alpha value of 0.05. A significant positive correlation was determined between the two variables with a correlation of 0.33, indicating a moderate effect size (p = 0.005). This suggests that as affective scores increase, cognitive scores also increase. Table 34 shows the results of the Pearson correlation, while Figure 16 shows the graph of cognitive scores as a function of affective scores with a trend line.

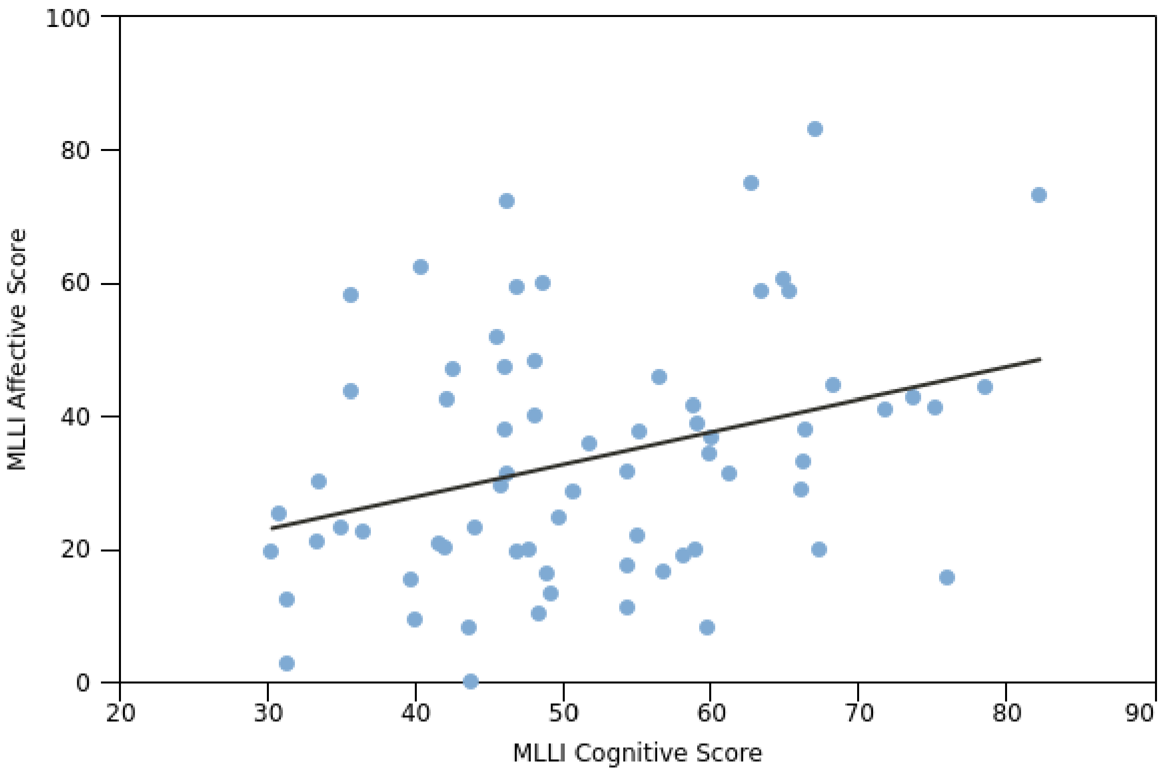
Table 34

Pearson Correlation Results Between Affective and Cognitive Scores

Combination	*r*	95.00% CI	*n*	*p*
Cognitive-Affective	0.33	[0.10, 0.53]	69	0.005

Figure 16

Scatterplot with Regression Line Added for Cognitive Scores as a Function of Affective Scores



The final testing series was conducted using Mann-Whitney Rank-Sum tests to review students coded as performing actual hands-on activity compared to their cognitive, affective, Student Fractional Inquiry Score, and meaningful learning. Initially, independent sample *t*-tests were to be used, but most variables displayed a break in normality when divided into categories. Mann-Whitney tests are based on the ranks of the data and do not have any distributional assumptions such as normality (Conover & Iman, 1981).

Based on an alpha of 0.05, the results for the tests are shown in Table 35. An alpha test value for this series of tests was 0.05. For cognitive (p = 0.199), affective (p = 0.623), meaningful learning (p = 0.353), and Student Fractional Inquiry Score (p = 0.085), it was determined that the distribution did not vary whether a student had hands-on activities at home.

Table 35

Results for Mann-Whitney Comparing Students Coded as Having Hands-On Laboratory Assignments During ERT

Class	No Hands-On Mean Rank	Hands-On Mean Rank	U	z	p
Cognitive Score	33.77	21.25	169.00	-1.28	0.199
Affective Score	33.30	28.50	140.00	-0.49	0.623
Meaningful Learning	33.56	24.50	156.00	-0.93	0.353
Fractional Inquiry Score	31.97	48.75	59.00	-1.72	0.085

Chapter Summary

This section discussed the results of the student and instructor surveys. Clean-up of the quantitative and qualitative data was reviewed, followed by tests for validity. Tests confirmed the practical use of the MLLI. Validity of the IRT was also discussed, with some issues noted. These will be elaborated upon further in Chapter 5.

Results from each portion of the survey were annotated, and the coding system was devised for the qualitative data. Using the IRT, the first null hypothesis was kept—there was no significant difference between the level of inquiry students experienced during ERT at El

Camino College. The second null hypothesis was rejected, indicating a statistical difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values. The third null was also rejected, indicating a negative correlation between the level of inquiry reported by students and their overall level of meaningful learning. Further breakdown of the qualitative codes was also performed, and several tests were performed to relate the experience students had during ERT in response to Research Question 4.

Given the broad level of results described in this chapter, Table 36 was compiled to show results for Research Questions 1–3. Each of these research questions had a hypothesis associated with it. Table 36 shows the particular research question, the different hypotheses, and what was held true. Notes specific to testing are also annotated, including what test was performed. For example, three different literature groups were tested for hypothesis B, some of which were not rejected.

Table 36

Compilation of Hypotheses for Research Questions 1–3 and Notes on Which was Held True

Hypothesis	Held True	Notes
Research Question 1 In terms of inquiry-based learning, what was the laboratory experience for students at El Camino College during ERT?		Shapiro-Wilk test conducted. Data skewed to lower levels of inquiry. Hyperlink to data
H_{o1}: There is no difference between the level of inquiry students experienced during ERT at El Camino College.	Yes	
H_{a1}: There is a difference between the level of inquiry students experienced during ERT at El Camino College.	No	
Research Question 2 Is the overall level of meaningful learning experienced by students at El Camino College during ERT similar to published literature values?		T-test conducted. Galloway and Bretz (2015), in-person general and organic. Enneking et al. (2019), hybrid general. Jones et al. (2021), ERT general.
H_{o2}: There is no statistical difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values.	No	Galloway and Bretz (2015) Cognitive/affective for in-person general and cognitive and cognitive/affective organic not different. All others, null rejected.
H_{b1}: There is a significant difference between the overall level of meaningful learning experienced in laboratory exercises	Yes (with exception)	Hyperlink to data

at El Camino College during ERT compared to published literature values.		
Research Question 3 Was there a link between the level of inquiry and the level of meaningful learning experienced by students at El Camino College during ERT?		Person R testing conducted. Negative correlation determined for all values. Hyperlink to data
H_{o3}: There is no correlation between the level of inquiry reported by students and the overall level of meaningful learning experienced in laboratory exercises by El Camino College students during ERT.	No	
H_{c1}: There is a positive correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.	No	
H_{c2}: There is a negative correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.	Yes	

In Chapter 5, these results will be expanded. Possible reasons for issues with the IRT and fixes will be discussed. The reasoning behind the quantitative and qualitative results will be discussed. Anecdotes from the qualitative data will be presented to elucidate students' phenomenological experience during ERT. Finally, the possible impacts of these findings will be discussed.

Chapter 5: Discussion and Conclusions

The previous chapter presented results from the instructor IRT and the complete student survey. This chapter presents a discussion of the results and elaboration on their causes. Issues with the IRT will be discussed, as well as possible corrections for errors found in the tool. The four research questions will also be answered based on these results and hypothesis analysis. Trends in the data and possible reasons behind them will be discussed.

Based on these findings, suggestions for policy change at El Camino college will be discussed. Further guidance for pedagogical changes will receive attention as well. Further applications of the results to the chemical education community at large will be broached. Finally, future work will also be described.

Inquiry Rubric Tool as a Survey Component

While the IRT was still used to evaluate research questions, initial results showed several problems. The Whole Number Score showed several errors, and specific error codes were developed to describe them. Whole Number values did not often match with their Fractional counterpart. In addition, triangulation was an issue when attempting to validate the IRT as a tool. Each will be discussed below as well as possible corrections for future work.

Evaluating IRT Issues

The first issue arising from the validation of the IRT was related to the Whole Number Score. The Whole Number Score was an attempt to link directly back to Buck et al.'s. (2008) work. The Whole Number Score had several errors associated with it. Regarding errors, this meant that something did not add up. For example, a student may have stated they had to determine the background information, yet instructors provided everything else. Of the ten instructors who took the IRT survey, six of the results returned errors. Of the

69 students who completed the survey, 33 returned errors. For instructors, this is a 60% error rate. For students, this was a 47.8% error rate.

The most common type of error amongst instructors and students was Type A, which meant that students had an unknown component but were told how to communicate these results. Using the guidelines set forth by Buck et al. (2008), Structured Inquiry (Level 0.5) is when there isn't a foregone conclusion at the onset of the experiment and when students choose how to present their results.

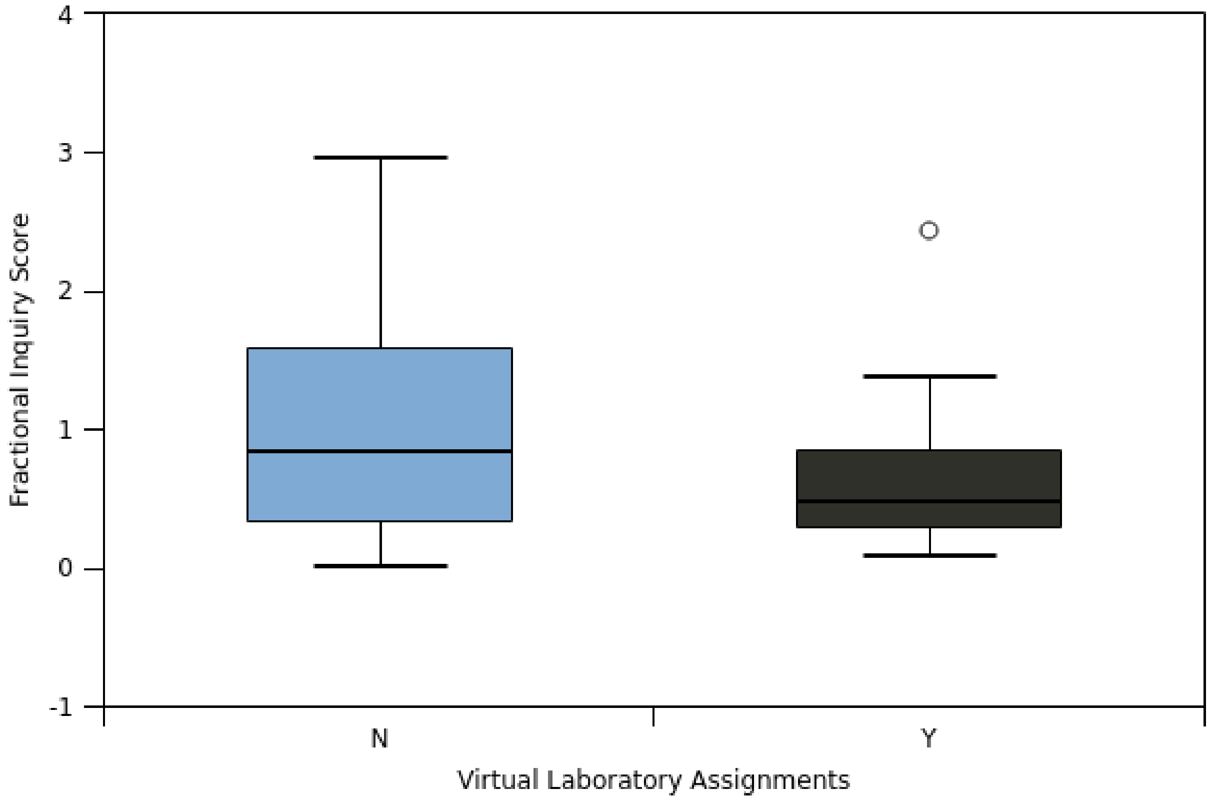
Students' other common errors included issues with Inquiry Questions #1 and #2. In essence, these questions shouldn't have been anything but 100%. Out of 229 chemistry laboratory activities that Buck et al. (2008) reviewed, 21 were level 1, only five were level 2, and none were level 3. Virtual laboratory activities, deeply investigative organic laboratory assignments, and hands-on activities may be able to reach Level 1 (Guided Inquiry). Reaching Level 2 (Open Inquiry) is difficult in an in-person situation, let alone in an online emergency environment. Students would have to develop a procedure in an environment with little hands-on experience.

From the qualitative data, only four students indicated that they had hands-on activities. Of the students who provided qualitative results, 19 stated they had interactive or virtual labs. It is not unbelievable that some of the students may have reached up to Level 1 inquiry. It is difficult to achieve a Level 2 assignment without some hands-on, yet eight individuals had a Fractional Rubric Score of 2 or higher. Five students had Whole Number Scores of level 3. These values do not make sense regarding the experimentation given to students based on the qualitative data.

Hands-on and virtual/interactive labs should have seen higher levels of inquiry. When performing an ANOVA evaluation of Fractional Rubric Scores as a function of the type of online instruction, the only significant value against an alpha of 0.05 was virtual laboratory assignments. ANOVA results were the opposite of what was expected. Results can be seen in Table 32 in Chapter 4 for all of the ANOVA analyses, but Figure 17 shows the results for just the Fractional Rubric Scores as a grouping of students who had virtual laboratories and those who did not. Students who indicated they had virtual labs generally had lower inquiry scores.

Figure 17

Fractional Rubric Scores Grouped by Qualitative Indicated Use of Virtual Laboratory Assignments



In addition to the Whole Number Score errors and issues with relatively high inquiry scores, attempts at triangulation generally failed or demonstrated unexpected results. Fractional Rubric Scores were cross-referenced with the MLLI questions related to inquiry. MLLI Question #3 (Made decisions about what data to collect), #22 (Interpreted my data beyond only doing calculations), and #31 (Learned problem-solving skills) showed no correlation. Question #7 (Learned critical thinking skills) had a significant negative correlation, and Question #4 (Felt unsure about the purpose of the procedures) had a significant positive correlation.

Inquiry-based instruction revolves around having students take prior knowledge and generate new information or solutions, have no 'correct' answer, and is reflective of facts, concepts, and models (Flick, 1995). Expected triangulation results for validation included positive correlations with MLLI Questions #3, #7, #22, and #31 and a negative correlation with #4. Results with triangulation were the complete opposite or non-correlative.

MLLI Question #4, indicated students with higher Fractional Inquiry Scores felt unsure about the purpose of their procedures. As the level of inquiry increases, students should feel more comfortable with the aim of their procedures as they have to contribute to their creation. Results showed the opposite here, where students felt unsure about what they were doing as their level of inquiry increased. MLLI Question #7 had a negative correlation, where students indicated they learned less problem-solving skills at higher levels of inquiry. Once again, this is the opposite of what was expected. As students were forced to work with unknowns, use their prior knowledge and create new information, they should have applied critical thinking scores more.

Further triangulation was attempted with the responses to the Qualitative Question #5: How much input did you have on what experiments were conducted and how they were conducted? Tell about the experience. Very few students wrote about the experience—most of the answers revolved around having little to no input. Of the students who gave appreciable responses, 52 stated that they had no input on their experimentation.

Student input is vital to inquiry. As instructors relinquish control and students gain it in response, inquiry increases. Yet a vast majority stated they had no control. ANOVA analysis shows no correlation between results, likely due to the low numbers for the other two codes associated with Question #5 (Some Input, n = 6 and Lots of Input, n = 3). Students at higher levels of inquiry should have had more input in their experimentation. This correlation was not seen.

IRT Error Causes and Corrections

Cronbach alpha testing was performed with the IRT scores, and tests between instructor and student scores were similar enough to allow for the Student Fractional Score to provide information regarding research questions. Yet, the IRT has several issues. It's helpful to understand the problems as related to the research conducted as they may influence quantitative results in unexpected ways. Possible fixes for future work are also presented for future iterations.

Based on the error results, it is most likely that the students misconstrued the questions. At no point during the survey were students told that the IRT assessed their level of inquiry. It is not unheard of for students to lack understanding in inquiry. For example, Chatterjee et al. (2009) looked to see if students could determine the difference between Guided and Open Inquiry. Of the 703 students surveyed, around 77.8% could identify guided-inquiry laboratories, but only 53.5% could identify open-inquiry. Fewer than half could identify both types of laboratories.

The inability to differentiate in this study was mainly because the intent of the IRT questions was not explicitly stated. This contributed to the errors witnessed in the IRT. Given the confusion and frustration students experienced while online, they likely believed they rated their feelings on the quality of the material the instructors gave them.

For example, 28 students were coded in the qualitative section as indicating they were confused. For instance, Student #32 stated:

> It was difficult to understand the purpose of such labs. For example when learning about reactions there was a specific lab where we virtually had to mix solutions and

observe color change. The websites settings were measured exactly with everything so there was no room for error and essentially no learning.

Yet, Student 32 had a Fractional Rubric Score of 2.1 (above Open Inquiry), and for Inquiry Question #1 (Given Background), they indicated 20%. Student #33 had a similar experience, indicating that the labs were sometimes hard to understand and confusing concerning calculations involved with the lab. They returned a Fractional Rubric Score of 1.2 and 55.0 % for Inquiry Question #1. In a similar occurrence, Student #35 stated "Very Difficult and confusing to understand what the professor wanted from us. Some of the experiments done would not bevery (sic) detailed or explain it well enough."

Student #35 indicated a 0% for Inquiry Question #1. The student had a Fractional Inquiry Score of 2.9, indicating that the student was almost in the Authentic Inquiry Level. This level of inquiry is nigh on impossible given the laboratory replacement work determined from the qualitative survey. Student #35 stated they only had worksheets that never made sense. Instead, the student likely gave 0% for their answers as they felt their instructor did not provide them with material or help the student. The student indicated that they had no good experience during their online period. This is not inquiry. Instead, the student should have felt in control of their work, that they provided the details of the experiment and did not rely on the instructor to do so.

This doesn't mean students coded with Confusing always had higher Fractional Inquiry Scores. For example, Student #26 indicated "I would describe my overall experience doing chemistry laboratory experiments online as confusing, frustrating, and indirect."

Student #26 had a Fractional Inquiry Score of 0.1, and for Inquiry Question #1, indicated 100%. This suggests that the student did not interpret the IRT questions as relating to how much material was given to them by their instructor; instead, they viewed it as the work they had to put into determining the background of the laboratory assignments. This was not an isolated situation. Yet, out of 37 students coded for Confusing, only 10 of them surveyed as 100% for Inquiry Question #1. Of the 37 students coded for Confusing, 12 had Fractional Inquiry Scores of 1.0 or above.

Misunderstanding the IRT questions is further supported by the relatively high Fractional Inquiry Score. Data was converted to ordinal values by binning the Fractional Inquiry Score and those presented by Buck et al. (2008) regarding chemistry laboratory assignments. A two-tailed Wilcoxon signed-rank test was significant based on an alpha value of 0.05 ($p < 0.001$). This indicates that the score differences are not likely due to random variation and that the literature values were significantly lower than those obtained from the Fractional Inquiry Score.

Three possibilities for correcting this discrepancy are presented. The first is to rewrite the questions to be active and have deeper explanations. A 0% and 100% example accompanied each question, but these should be expanded. A more active approach may help the student see personal involvement in inquiry, not base their answers on what the instructor gives them. For example, Inquiry Question #3 (Procedure and Design) originally stated, “how often were procedures/directions given to you during experiments?” This could lead students to mark low percentages when they felt their instructor didn't thoroughly explain the directions or were confused about the instructions. Instead, the question should be rewritten as “how often did you design a procedure for your experiments?” This adds an active role to the student, makes them think of their role in the experience, and helps alleviate the confusion.

In addition to this correction, the complete removal of Inquiry Questions #1 and #2 are suggested. A student will rarely design a research study and review background information in the literature at the community college level. Buck et al. (2008) found no experiments in the chemistry laboratory textbooks they reviewed that fell under Level 3.

Inquiry Questions #1 and #2 were set to 100% for all students, and the Fractional Rubric Score was recalculated to prove further the removal of the questions as a beneficial procedure. Note that this was done only to test the relevance of Inquiry Questions #1 and #2—during the rest of this study, the questions were included in the Fractional Inquiry Score.

When the values are set to 100%, the Fractional Inquiry Score's average drops to 0.63 compared to 0.87. In addition, the standard deviation lowers from 0.72 to 0.49 in the modified score. Furthermore, when tested against the values dictated by Buck et al., the Wilcoxon signed-rank test does not show any significant difference between the values. Results for both Wilcoxon Signed Rank tests and descriptives are shown in Table 37. This indicates a portion of the issue for the IRT was the inclusion of Inquiry Questions #1 and #2, as well as their interpretation by students.

Table 37

Wilcoxon Results for Ordinal Inquiry Scores from Buck et al. (2008) Compared to Fractional Rubric Score and a Modified Rubric Score Excluding Questions #1 and #2 of the IRT

Variable	*M*	*SD*	V in Wilcoxon Compared to Buck et al. (2008)	z in Wilcoxon Compared to Buck et al. (2008)	p in Wilcoxon Compared to Buck et al. (2008)
Student Fractional Inquiry Score	0.87	0.72	2,265	-6.32	< 0.001
Modified Fractional Inquiry Score	0.63	0.49	720	-1.21	0.228

Another modification to the IRT that may be beneficial in the future is to change the weight of the questions. This is not unprecedented, as the inquiry rubric used as the basis for the IRT saw different iterations and was built on previous literature. Herron's (1971) Level of Openness in the Teaching of Inquiry had three guiding factors and four levels. Similarly, Fay et al. (2007), whom Bretz co-wrote with, had four different levels based on three distinct components. A rearrangement of weighting may benefit the IRT.

Applying this rearrangement would benefit the two components of Level 0.5—Conclusions and Results Communication. Often, students indicated the presence of unknowns in their work (mean score of 52.01) but were repeatedly told how to communicate them (mean score of 73.20). Changing the question weight by combining the two components into a single question alleviates the most common type of error, Type A. Type A error was when a student had an unknown but was told how to communicate the results.

As indicated above, removing Inquiry Questions #1 and #2 affects the total number of errors with the Whole Number Score. First, it drops the total count from 35 to 30. It increases Type A from 10 to 14. Seven error codes are due to Inquiry Question #5 (Results Communication). This means that by adjusting the weighting, the error level in the Whole Number Score would drop drastically, allowing for better data comparison.

IRT Validity Conclusions

Results indicated that the IRT was usable but had associated errors. As a new tool, this was not wholly unexpected. The first significant source of error discussed included a misunderstanding regarding the intent of the questions by some students. The second was an issue with grouping Inquiry Questions #5 and #6 to make Inquiry Level 0.5. To alleviate the problems, the following is proposed for future work:

- Rewrite questions to make them active to the student, not what the instructor did.
- Remove Inquiry Questions #1 and #2 as there is little chance a student experienced Level 3 Inquiry at a community college level.
- Combine Inquiry Questions #5 and #6 into a single question.

While the IRT has faults and can be improved in the future, validity testing showed that it is usable for this research. The first research question will be addressed in the next section, and the findings will be discussed as they relate to the IRT and the student experience.

Research Question #1

For this study, Research Question #1 delved into the experience students had regarding inquiry. The research question and corresponding hypotheses were:

- RQ1: In terms of inquiry-based learning, what was the laboratory experience for students at El Camino College during ERT?
- H_{o1}: There is no difference between the level of inquiry students experienced during ERT at El Camino College.
- H_{a1}: There is a difference between the level of inquiry students experienced during ERT at El Camino College.

Results supported the null. To determine hypothesis support, a Shapiro-Wilk test was conducted to determine distribution. Fractional Inquiry Scores did not follow a normal distribution and skewed towards lower scores. The mean of the Fractional Inquiry Scores for students was 0.87 with a standard deviation of 0.72. The lowest average score for the IRT questions was Inquiry Question #6, with a mean of 52.01. The highest average score for the IRT was Inquiry Question #1, at 79.29.

According to the histogram shown in Figure 11 in Chapter 4, most students experienced inquiry levels between Level 0 and Level 1. Table 38 shows the Fractional Inquiry Scores binned based on Inquiry Level. Of the 69 students with usable quantitative data, 29 rated between 0 and 0.5 (Level 0, Validation), 16 rated between 0.5 and 1 (Level 0.5, Structured Inquiry), 16 between 1 and 2 (Level 1, Guided Inquiry), eight between 2 and 3 (Level 2, Open Inquiry) and 0 at Level 3 (Level 3, Full Inquiry).

Table 38

Binned Values for Student Fractional Inquiry Score

Variable	*n*	%
Level 0 (Validation)—Scores 0–0.5	29	42.03
Level 0.5 (Structured)—Scores 0.5–1	16	23.19

Variable	*n*	%
Level 1 (Guided)—Scores 1–2	16	23.19
Level 2 (Open)—Scores 2–3	8	11.59
Level 3 (Full)—Score 3	0	0%

Table 38 shows that most students experienced (65.22%) low levels (Fractional Rubric Score between 0–1) of inquiry during their online chemistry laboratory courses. This matches similarly to the qualitative data collected in the student survey. Watching videos, performing data computation with pre-generated data and worksheets should be considered low inquiry. Generally, students would not develop procedures with this type of assignment (Level 2), though they may need to determine how to analyze the data (Level 1). These types of replacement tasks may allow for unknowns to be determined. For example, a student may be given titration data and generate a titration curve. Given a mass and moles of an acid or base determined from a titration curve, the student could determine an unknown acid identity from a list using molar mass.

Table 30 in Chapter 4 shows the results for students coded for a certain type of laboratory exercise. A large number of students were coded for videos (*n* = 34) and for worksheets (*n* = 38). This isn't to say that either is devoid of inquiry. For example, Student #14 was coded for both worksheets and videos. The student stated “most of these labs had worksheets associated with them, where data had to be filled out, calculated and interpreted.”

The student indicated that they must use the data and form their own conclusions. This student's quantitative data showed a Fractional Inquiry Score of 0.7. Given what the student related, it makes sense that their experiments would be between Structured and Guided. The student did not come up with the procedure, but there would be the 'core of doubt' Schwab (1962) stated was vital to inquiry.

As stated in the validation portion of the IRT, some of the higher scores may have been due to students not understanding the relationship of the inquiry questions. For example, Student #35, coded for worksheets, had a Fractional Inquiry Score of 2.9. They stated for the laboratory assignments, they had “worksheets, then (sic) never made any sense.”

In the qualitative work, some students indicated that they performed interactive experiments ($n = 19$), and few students performed hands-on experimentation ($n = 4$). These experiments should have had higher inquiry levels. Many interactive programs such as Labster have simulations that allow students to explore unknowns and develop their own investigations. For example, Labster offers an acid/base experiment where students can explore the pH level of food and naturally occurring substances. Programs such as labs in ChemCollective provide students with glassware and chemicals but don't have any walkthrough on how to perform an experiment. The expectation is that these types of investigations should provide a higher level of inquiry.

As noted in Figure 17, students generally had lower levels of inquiry when using virtual experimentation. This may be due to the confusion with the inquiry-based questions pointed out in the IRT Validation section. Still, some qualitative results indicate that students did not obtain much information from virtual experimentation. For example, Student #39, with a Fractional Rubric Score of 0.3, indicated “I didn't fully understand the procedures in laboratory experiments or what the results meant. … Interactive demos and worksheets. Completing them didn't require much understanding.”

These qualitative results indicate a shallow level of inquiry. The student did not perceive unknowns and viewed the virtual labs as simplistic. Quality may have also played a role. Student #40 indicated they also had virtual labs and simulations but were “pretty bad, and it was boring.” In addition, the student stated “we did titration simulations were was (sic) kind of cool since the website used didn't lag…”

This last comment related to one of their earlier mentions that the website they worked with kept doing “weird stuff and making my data off.” Student #17 indicated a lack of interest in the virtual laboratories well. The student had a Fractional Inquiry Score of 0.6 and indicated “I also did have some virtual lab, but I found them tedious and did not pay to (sic) much attention to them.”

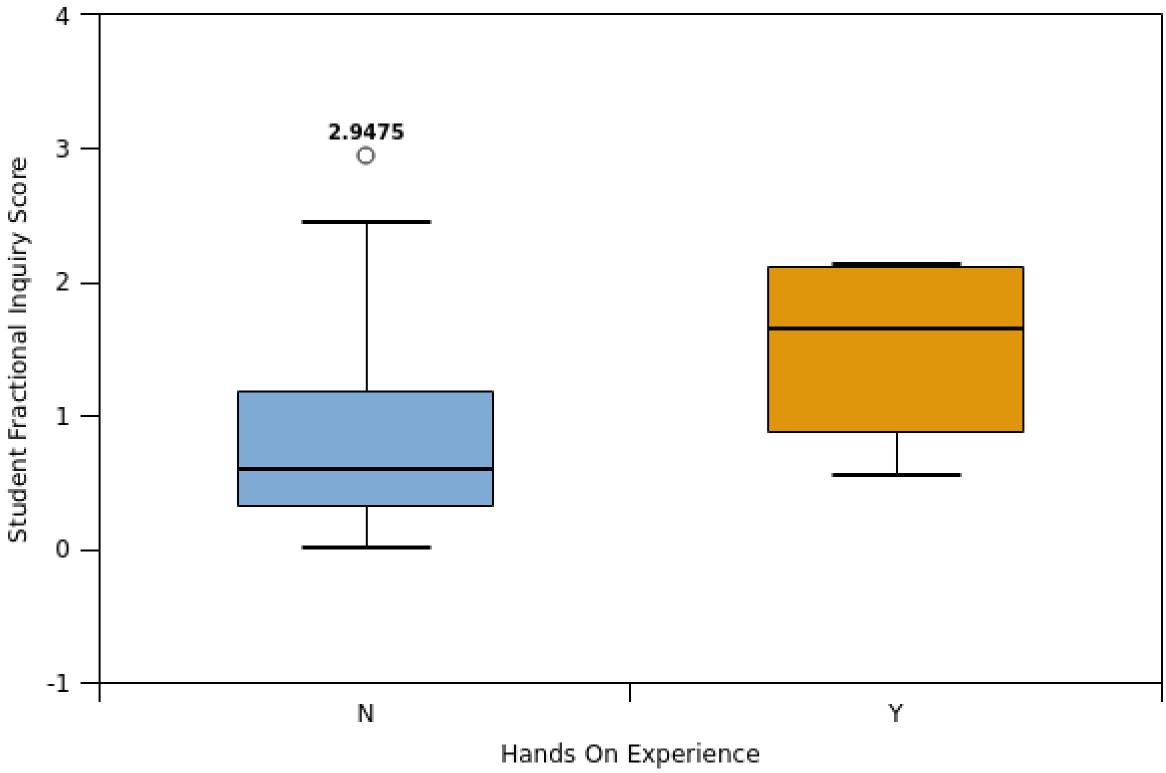
Student #61 had the highest Fractional Inquiry Score (2.4) and was also coded for Virtual Labs. The student coded for Confused, Negative Experiences and twice for No Good Experience. This high Fractional Inquiry Score relates to the student not understanding what the IRT questions were based on and describing a frustrating experience instead. In regards to the lab, the student stated “it was really confused (sic), frustrated, and felt dumb doing the labs. Interactive demos, it wasn't a bad thing but I feel it would've been better to see in person.”

These findings indicate that students at El Camino College did not have an inquiry-based experience using virtual experiments. The labs appeared to be frustrating and lacked any content with which the student could identify. It is possible that the sites that the instructors used were broken, as indicated by Student #17. Students may also have longed for a real hands-on experience, as indicated by Student #61.

Only four students were coded for actual hands-on activities. While Fractional Inquiry Score between students with hands-on and those without were not statistically different, this is very likely due to the low n value for students with hands-on. Figure 18 shows a box plot comparing the Fractional Inquiry Score with those who did and did not have hands-on laboratories. Of the reported types, it was expected that hands-on activities would most simulate the experience in a real laboratory and therefore be higher in terms of inquiry. The four students who indicated they had hands-on experience had Fractional Inquiry Scores of 0.5, 1.2, 2.1, and 2.1. Again, while not statistically different, it is an essential item to note to begin comparisons to the literature.

Figure 18

Boxplot Comparing Fractional Inquiry Scores of Those Who Had Hands-On Activities During ERT to Those Who Did Not



Inquiry Literature Comparison

While the IRT is new for this work, there is relatability to the literature. In particular, types of experimental experiences during COVID-19 in chemistry laboratories were of interest. How specific experimental techniques relate to inquiry was of import. In addition, what experiments were reported in the literature during COVID-19 provide insight into the level of inquiry experienced by the students at El Camino College.

Data collection and worksheets in terms of inquiry would likely fall into either Level 0 (Validations) or Level 0.5 (Guided). These experiments did not see widespread use before the pandemic as replacement exercises, only supplementary exercises. During the pandemic, large-scale data computation was seen in the literature (Perri, 2020). In Perri's (2020) work, students generated random absorbance data in a Beer's Law experiment and proceeded with the experiment as if they had collected the data. To introduce randomization and an unknown into the lab, the authors added a RAND() function. This shows that it is possible for there to be some inquiry involved with data computation. The outcomes aren't entirely predictable, and students can use the data generated to explore absorbance.

In this study, while not significantly different, the mean Fractional Inquiry Score of those who performed data computation (M = 0.345) was lower than those that did not (M = 0.700). Results show that while it is possible to add some inquiry into large-scale data computation as Perri (2020) did, this was not common amongst the students at El Camino. In this case, the experience of El Camino students with data computation was likely to be at a lower level of inquiry than those in the literature.

A literature review has shown that pre-recorded videos may help in the laboratory (Gryczka et al., 2016; Jolley et al., 2016; Lamichhane & Maltese, 2019), but as Woelk and Whitefield (2020) note, this leaves students as passive observers. This is the opposite of inquiry, where students are engaged in making observations and testing hypotheses. Woelk and Whitefield (2020) attempted to alleviate this passiveness by performing synchronous, live experimentation and reported positive results.

The results of the students at El Camino college show that very few students had synchronous videos to watch based on the qualitative data. The Watching Instructor code only appeared three times throughout the qualitative data. For example, Student #1 stated, “My teacher did the experiments, and we just observed.”

There is a chance that this was not synchronous but recorded. Pre-recorded videos would make for a passive experience with the student not having a voice during the experimentation. Some students indicated they recorded results and attempted to identify unknowns, but for most students, it appears as though they had a weak form of inquiry regarding video watching. Once again, like data computation, El Camino students experienced less inquiry than the literature using this technique.

Ali and Ullah (2020) summarized many benefits of virtual experimentation. In particular, gamification is possible, adding a layer of inquiry to the system by making the lab fun and inventive. In addition, Ali and Ullah (2020) noted that virtual laboratories could be realistic. This means that virtual labs should have been one of the higher forms of inquiry-based experimentation in this study, yet the opposite was seen. Students found the experiments tedious, low in inquiry, and a general malaise involved with them. This may be due to the poor quality of materials as indicated by Student #40 or how instructors implemented them. Regarding the literature, it would again seem that El Camino College students experienced lower levels of inquiry than expected, even when using this type of intervention.

The final intervention, and likely the highest in terms of inquiry, was at-home chemistry experimentation. In this type of experimentation, students get exposed to working with their hands. Kennephol (2007) noted that with at-home experimentation, students could contextualize their experiments—an essential component of inquiry. Students should be able to take what they learn, apply critical thinking skills, and increase their overall knowledge level through exploring an unknown. Kelley (2021a) developed at-home experiments where students had to design their own investigations. In terms of Buck et al. (2008) 's inquiry rubric, this would qualify as a Level 2 experiment. While students at El Camino did not indicate that they developed experiments, the four students responding to this work's survey with hands-on activities had higher levels of inquiry regarding the Fractional Inquiry Score.

After the call by the American Chemical Society for articles based on the experience instructors had during the COVID-19 pandemic, laboratory experiences were compiled by

Kelley (2021b). Counts of the different types of interventions detailed in the articles were tabulated. Of the major types of laboratory curriculum Kelley (2021b) determined from the literature review, interventions at El Camino College included first-hand experiments, second-hand experiments, simulated experiments, sample data analysis, and practice problems (worksheets).

Of the 91 articles that Kelley (2021b) reviewed, the highest count was second-hand experimentation which could include watching videos or reading procedures that are not interactive. This was found in 50.5% of the articles. The next highest was simulated experiments, counted in 45.1% of the articles. First-hand experimentation was seen in 29.7% of articles, and data analysis was found in 36.3%. Replacement exercises like worksheets were not totaled as most articles contained some inclusion of this intervention. The other interventions described by Kelley (2021b) are not discussed here as they were not used at El Camino College.

From the information above, the expectation is that first-hand experimentation and virtual experimentation would have the highest levels of inquiry, followed by second-hand experimentation, then data analysis. Worksheets would provide the lowest level of inquiry, given that it is essentially not a laboratory exercise. Compared to the types of intervention found in the literature, the highest count in this study was Worksheets (n = 38, 55.07%), then second-hand experimentation via the watching of videos (n = 34, 49.28%). Virtual labs was the next highest count (n = 19, 27.54%) followed by data computation (n = 10, 14.49%) then finally actual experimentation (n = 4, 5.80%).

From a non-statistical standpoint, second-hand experimentation counts appear similar to those found in Kelley's (2021b) observations. Aside from worksheets, this was the dominant form of laboratory instruction at El Camino College. Virtual labs and data analysis were lower than those reported by Kelley (2021b), but the most significantly different was hands-on. While these percentages are not statistically comparable, from a qualitative standpoint, it can be assumed that students at El Camino College had lower levels of inquiry than those reported in the literature. Virtual and hands-on activities would provide the highest level of inquiry yet were two of the lowest type of experiment replacements used. The percentage of students reporting that they had the higher inquiry (virtual/hands-on) experimentation was much lower than the percentage of articles reported by Kelley (2021b).

Research Question 1 Conclusions

Research Question #1 stated: In terms of inquiry-based learning, what was the laboratory experience for students at El Camino College during ERT? Based on the IRT results and qualitative assessment, it was assessed that students did not have much variance in their experience during ERT with online chemistry assignments. Most students experienced low levels of inquiry. Assignments often meant to elicit higher levels of inquiry did not seem to do so for students at El Camino College, particularly compared to the literature. High levels of confusion indicated in the qualitative data and poor-quality materials may have contributed to this.

It must also be taken into account that scores on the IRT may well be overly high due to confusion about the questions and their intent as described in the validation of the IRT. Therefore, the actual level of inquiry experienced by students is even lower than what the Fractional Rubric Score indicates. Overall, students at El Camino College experienced low levels of inquiry. How this affected them will be discussed with Research Question 3. Before this, the results of the MLLI must be addressed.

Research Question 2

The second research question for this study took a quantitative approach to the experience that students had while in an ERT environment at El Camino College. The MLLI tested the student laboratory experience. The following research question and hypotheses were created:

- RQ2: Is the overall level of meaningful learning experienced by students at El Camino College during ERT similar to published literature values?
- H_{o2}: There is no statistical difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values.
- H_{b1}: There is a significant difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values.

As shown in Chapter 4, the null was rejected for most of the literature values tested. Three series of data sets were evaluated against the null hypotheses. The first was from the creation of the MLLI and included post-tests given to students at the completion of both general chemistry and organic chemistry courses (Galloway & Bretz, 2015a). The second contained four data sets from an in-person and hybrid general chemistry class (Enneking et al., 2019). The final was another class forced into ERT during the COVID-19 pandemic (Jones et al., 2021). Results of null hypothesis rejection can be found in Tables 23–26 in Chapter 4.

Tables 23–26 show that all of the affective-based *t*-tests revealed significant differences between those in the literature, with the current study having lower affective values. All but one of the cognitive-based t-tests rejected the null. In their organic class, the one cognitive score that was not rejected was in Galloway and Bretz (2015a). Two cognitive/affective tests were not rejected; both were from the Galloway and Bretz (2015a) work.

It is interesting to note that Galloway and Bretz (2015a) did both pre- and post-testing as a part of the MLLI development. Students were tracked across a semester and took the MLLI before the semester began, then again after. Their results showed that students often had unfulfilled expectations within all three domains decreasing across the semester. Galloway and Bretz (2015a) also indicated that organic students generally scored lower on all accounts but that "both courses responded that their experiences that failed (sic) to meet their expectations" (Galloway & Bretz, 2015a, p. 1156). The authors did not elucidate why the organic class's cognitive value scored lower, but this lower score is why the null was not rejected in this study.

To explain why El Camino students did not differ from Galloway and Bretz's (2015a) report, another paper of theirs was reviewed. In another study that year, Galloway and Bretz (2015b) administered the MLLI nationwide for both general and organic courses. MLLI results showed similar findings, with negative changes between pre- and post-class measurements. Once again, organic chemistry was lower across all scores than general chemistry. This study looked at cluster analysis to detect when expectations were fulfilled and unfulfilled. The organic chemistry cognitive score was 5% higher in the national study compared to the MLLI development study. Although there was an increase, it was not significantly higher than their other study. The second national study helps explain why the cognitive score wasn't considerably different compared to this study.

Galloway and Bretz (2015b) divided up clustered scores into different categories – high, mid, and low. When reviewing the different clusters, Galloway and Bretz (2015b) looked at questions that indicated expectations went unfulfilled, meaning that they would be a lower value for the final score. Table 39 shows whether student expectations went unfulfilled and what cluster is referenced. Possible results are “Yes” (student expectations were generally fulfilled), “No” (student expectations went unfulfilled), and “Mixed” (there was a mixture of fulfillment and unfulfillment).

In addition, in Table 39 are comparisons done internally for this study and to Galloway and Bretz (2015b). In the *intrastudy* portion, a particular question was compared to the mean cognitive store. If the question was higher than the mean (H), it contributed to increasing the cognitive score. If a value was lower than the mean in the El Camino study (L), then the question contributed to a lower mean. For example, the mean cognitive score in this study was 52.04. MLLI Question #7 had an average of 54.94; therefore, it was marked as “H.” MLLI Question #3 had an average of 41.57, consequently was marked as “L.” In addition, the individual question values in this study were compared to Galloway and Bretz (2015b), who reported values for the individual questions. Whether values in this study are higher (H) or lower (L) are shown in Table 39. Starred values are noted as significantly different from this in Galloway and Bretz (2015b).

Table 39

Comparison of Clustered MLLI Cognitive Question Results in Galloway and Bretz (2015b) with Both Intrastudy and External Comparison

Variable	Organic Chemistry Low	Organic Chemistry Mid	Organic Chemistry High	Intrastudy	Compared to Galloway & Bretz
Question #3 Made decisions about what data to collect.	Yes	Yes	Yes	L	L
Question #5 Experienced moments of insight.	Mixed	Yes	Yes	L	L
Question #7 Learned critical thinking skills.	Mixed	Yes	Yes	H	L
Question #10 Considered if my data makes sense.	Yes	Yes	Yes	H	H
Question #17 "got stuck" but kept trying.	Yes	Mixed	Mixed	H	H**
Question #19 Thought about chemistry I already know.	Mixed	Yes	Yes	H	H

Variable	Organic Chemistry Low	Organic Chemistry Mid	Organic Chemistry High	Intrastudy	Compared to Galloway & Bretz
Question #22 Interpreted my data beyond only doing calculations.	Mixed	Yes	Yes	L	L
Question #25 Used my observations to understand the behavior of atoms and molecules.	Mixed	Mixed	Mixed	L	L
Question #26 Made mistakes and tried again.	Yes	Yes	Yes	H	H**
Question #31 Learned problem-solving skills.	Mixed	Yes	Yes	H	L

It is very likely that the two starred values, MLLI Question #17 and Question #26, raised the cognitive score in this work high enough not to be significantly different from Galloway and Bretz (2015b). These two values were extremely high in this study (76.49 and 77.57, respectively), indicating that many students liked the ability to repeat experiments online. They were not forced to complete labs during a specific period and could try again if they got poor answers. MLLI Question #3 likely balanced out the cognitive score a bit, showing that students at El Camino did not have much choice in their work, again denoting a relatively low level of inquiry. For the others, each of the lows compared to Galloway and Bretz (2015b) had at least one “Mixed” response where many students did not have their expectations fulfilled, relating to a lower post-semester cognitive score.

Regarding the lack of difference in cognitive/affective scores compared to Galloway and Bretz (2015b), the most likely reason is the overlap between cognitive and affective. Galloway and Bretz (2015b) ignored cognitive/affective results for cluster testing because the clusters they saw had less cohesion due to the overlap of the domains. This is the most likely reason cognitive/affective scores were not significantly different compared to Galloway and Bretz (2015b). Results for the average affective score were low in this study (33.70), while cognitive was higher (52.04). The cognitive/affective domain was between the two values, at

44.75. The cognitive overlap during this study likely raised the value enough that it created the difference seen compared to Galloway and Bretz (2015b). In addition, it is essential to note that normality for the cognitive/affective values in this experiment was broken, which may make *t*-tests unreliable. This is a possible minor contributor to the compared values.

For the cognitive scores, the results in this study were significantly lower than those reported by Enneking et al. (2019) and Jones et al. (2021). In the Jones et al. (2021) work, both traditional and hybrid laboratory classes were given the MLLI. The hybrid approach consisted of face-to-face instruction as well as virtual laboratory assignments. Virtual laboratory assignments consisted of 16 virtual laboratories available from LearnSmart Laboratories. Experiments consisted of core concepts followed by simulations where students could virtually use glassware and make experimental measurements.

While face-to-face is likely a significant contributor to the much higher cognitive score, students were able to take advantage of virtual laboratories that were designed to improve their skills. These labs contained adaptive questions and provided reports on what the students needed to improve. This allows deeper engagement to fit the student better and develop their cognitive skills. Some have noted that a virtual experiment can match teaching in laboratories (Makransky et al., 2016), particularly when virtual experimentation is combined with in-person activities.

Enneking et al. (2019) noted discrepancies in their work between traditional laboratories and the hybrid cohort. Like Galloway and Bretz (2015a), Enneking et al. (2019) obtained pre- and post-semester values for the MLLI and compared the values. The traditional cohort showed some improvement in expectations after the semester, but across the board, the hybrid cohort showed a decrease. Enneking et al. (2019) believed the declines they noticed were due to not having a complete hands-on experience compared to the more traditional cohort. Enneking et al. (2019) further indicate that they believe the lack of expectation fulfillment is due to an overall experience and not just a singular inclusion or omission of a laboratory experiment.

For the El Camino study, it is the opinion of the author of this work that one of the major contributing factors to the higher cognitive score in Enneking et al. (2019) and the positive results in Makransky et al. (2016) was the well thought out experience that students were given. The hybrid course was well planned, whereas the ERT situation forced instructors to change their teaching approach to accommodate in-person closures rapidly. Similarly, the MvLab experimentation described by Makransky et al. (2016) was planned and executed with interpersonal communication between students and available tutors during the online portion.

Jones et al. (2021) provides a unique chance to compare the experience students at El Camino College had in the laboratory, as both were conducted during the COVID-19 pandemic in ERT. As previously indicated, the cognitive scores in this study were lower than those in Jones et al. (2021). Jones et al. (2021) used a series of virtual labs, simulations, and video libraries to perform the experiments. Their significant difference of note was the use of synchronous laboratories. The authors stated that they had attempted an asynchronous experience the previous semester and found the lack of instructor-to-student and peer-to-peer interactions determinantal to student learning. Jones et al. (2021) compared their cognitive and affective values against Enneking et al. (2019) as well as Galloway and Bretz's (2015b) national scores. They state that their values fall well within the range reported by these individuals. Furthermore, they postulate that this is demonstrative that online learning in the cognitive domain can be at least as effective as traditional learning.

Once again, collaborative work and well-planned experiences likely contributed to the higher scores than El Camino College. In addition, the synchronous activity probably was a significant factor. In this study, it is unclear whether students worked synchronously or asynchronously on laboratory assignments unless explicitly stated so in the qualitative section. For example, Student #51 said:

> During an experiment that had to deal with the reactions of mixing chemicals and recording the data of color change, my lab-mates and myself took bets on what reactions would occur. This made the lab more entertaining, and was able to notice patterns within chemical reactions.

From the qualitative statement, it can be determined that the student watched a live video with his classmates. Unfortunately, not enough students indicated similar experiences to attempt to codify those who had synchronous work vs. those who had asynchronous work. An attempt was made to group those who noted group experiences as an indication that there was at least some collaborative work. A two-tailed Mann-Whitney test for average cognitive scores as a function of those who indicated they had group work was then performed. While those that showed they had some group work had a slightly higher mean cognitive score (53.10 vs. 51.74), the differences were not statistically significant ($p = 0.606$).

Regarding affective scores, students at El Camino College scored lower than the three compared literature sets. This is further backed by the number of negative codes—an average of 2.78 ($SD = 1.42$) compared to the number of positive codes per student, an average of 1.23 ($SD = 1.06$). There is a correlation between the number of negative codes and affective and meaningful learning scores (see Table 33 in Chapter 4). As negative codes increase, the student's affective score decreases. Many students reported issues with instructors ($n = 16$), while others reported having no good online experience ($n = 19$). Students reported difficulty relating the material to what they were doing ($n = 25$), and many saw what they did in their lab-based assignments as unimportant ($n = 11$).

A portion of the lower affective scores is likely related to the stress caused by COVID-19 and the movement online. Petillion and McNeil (2020) noted that over 70% of students in their survey indicated they experienced high stress levels due to the move to ERT. This cannot be the only contributor to the lower scores, as Jones et al. (2021) showed significantly higher affective scores than students at El Camino College.

Regarding the affective questions, the most significant contributors to the low score were MLLI Questions #21 and #13. MLLI Question #21 related to how frustrated a student was. As indicated in the qualitative data, this could be due to an issue with instructors, with sixteen students reporting this code. In addition, students could not relate the material to what they were doing, further leading to a frustrating experience. MLLI Question #13 asked the student to rate how much confidence they had in the laboratory.

Given that most students did not have any hands-on experience, this is no surprise. Furthermore, being unable to relate the material to what they were doing likely contributed to this low score. Overall, the negative experiences students reported significantly impacted the students' affective scores and led to a lack of meaningful learning.

Research Question 2 Conclusions

As a final component to this research question, it is essential to look back to Novak's (1998) notation that meaningful learning occurs when there is an overlap between the cognitive, affective, and psychomotor domains. Research Question #2 asks if there was an overall difference in meaningful learning levels compared to the literature. Given that students during ERT at El Camino barely engaged in the psychomotor domain with minimal hands-on activities, overall scores were generally lower in the cognitive and affective domains; yes, there was a significant difference in levels of meaningful learning. During ERT, students at El Camino College had lower levels than those in the literature.

There were several factors contributing to these results. The pandemic put students in an unknown position, both in school and in their everyday lives. This causes higher stress levels, yet, at El Camino College, affective and cognitive scores were lower than those published by Jones et al. (2021), meaning there were more factors. High levels of confusion, frustration, and other negative feelings were major factors displayed in both the MLLI survey and the qualitative questions. The possible lack of synchronous activities may also have contributed to these low values. Low-quality materials and lack of instructor support were also mitigating factors.

With literature results of the MLLI scores completed, further evaluation of the levels of inquiry was conducted. To accomplish this, MLLI and the IRT scores were compared. In the next section, the related research question and hypotheses are discussed.

Research Question 3

The third research question attempts to correlate the experience students had in terms of inquiry with meaningful learning. The research question and hypotheses are as follows:

- RQ3: Was there a link between the level of inquiry and the level of meaningful learning experienced by students at El Camino College during ERT?
- H_{o3}: There is no correlation between the level of inquiry reported by students and the overall level of meaningful learning experienced in laboratory exercises by El Camino College students during ERT.
- H_{c1}: There is a positive correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.
- H_{c2}: There is a negative correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.

Pearson R analysis was conducted between cognitive, affective, cognitive/affective, and the overall average for the MLLI compared to the IRT Fractional Inquiry Score values. All the scores showed a significant negative correlation between their MLLI scores and the

Fractional Inquiry Score. This means that the null was rejected, and hypothesis C_2 was held valid. Results for this can be found in Table 27 of Chapter 4.

When first building this work, the expectation was that students with higher levels of inquiry at a minimum would show higher cognitive scores with the MLLI. In addition, it was believed that affective scores would be higher as Kelley (2021b) reported that students who had hands-on activities (and therefore, higher levels of inquiry) had stronger positive feelings about chemistry during the COVID-19 pandemic. Also, many literature sources have shown that when students conduct inquiry-based experimentation, they generally have a better attitude (Abraham, 2011; Blanchard et al., 2010; Cacciatore & Sevian, 2009; Deters, 2005; Hall & McCurdy, 1990; Leonward, 1983).

Results from this study showed the opposite. For all domains, the scores decreased as the perceived level of inquiry increased. Regarding the cognitive side, the most likely reason is a lack of understanding that came along with the inquiry. This is supported by the scores in individual cognitive questions, shown in Table 19 of Chapter 4.

Reviewing these values, the lowest contributors to the score, those who brought the cognitive value down, were MLLI Questions #16, #24, and #29. Question #16 was "…to be confused about the underlying concepts," Question #24 was "… to focus on procedures, not concepts," and Question #29 was "to be confused about what my data meant." Two of these questions dealt with confusion about what students were doing. In addition, one of the qualitative codes dealt with how confused students were. Out of the 65 qualitative data sets, 37 students were coded for being confused.

This type of result is not wholly unexpected. Novak (1998) noted that rote learning over inquiry learning is often used due to its ease. Similarly, Herron (1996) stated that chemistry students prefer rote learning over inquiry because it requires less cognitive effort. Given the difficult circumstances with a rapid move to ERT, coupled with the stress students experienced due to the pandemic, the seed of doubt often introduced by inquiry may have negatively influenced students. Furthermore, this confusion bled into the affective domain.

A Mann-Whitney test was performed to see if there was a relationship between confusion levels reported in the qualitative data and the average affective scores for students. An alpha value of 0.05 was used, and the results showed a significant difference ($z = -2.28$, $p = 0.023$). Those coded with the Confusing code had lower affective scores than those who did not. This is a major contributor negative correlation with the level of inquiry.

Another major contributor that has been previously discussed is the method of delivery. It has been noted that the actual level of inquiry is lower than what was determined by the IRT. Most students engaged with activities that would be considered low inquiry. Only four students had hands-on activities. Kelley (2021b) stated that students who had hands-on activities in their studies generally felt very positive about them. With such a lack of hands-on experience, lower affective scores are possible even with inquiry.

Regarding hands-on, 24 students indicated, unsolicited, that they wished for some type of an in-person experience or noted that the experience would be different with hands-on. This desire for hands-on likely contributed to the negative correlation with the affective domain. For example, Student #33 stated, “the labs were sometimes hard to understand because we weren't physically doing them.”

Additionally, results from the ANOVA analysis of laboratory techniques against the Fractional Inquiry Score indicated that the only method with significant population differences was virtual laboratories, which was the opposite of what was expected. Students who used virtual experimentation showed lower Fractional Inquiry Scores. Low-level inquiry scores coupled with virtual experimentation goes against a report by Caños de las Heras et al., (2021), who stated that students performing virtual laboratories were highly motivated and felt engaged by the lab. At El Camino College, the experience appears to be the opposite; a possible explanation is using low-quality materials and not understanding what they were doing.

Of the 65 students who gave qualitative data, 16 were coded as mentioning the materials they were working with were of low quality. If a student had problems with the interactive labs, this would lead to lower cognitive and affective experience. For example, Student #41 stated, “we used interactive demos and simulations online. The quality was pretty bad, and it was boring.”

Some students may also have viewed these virtual labs as useless or easy. Student #23 indicated that their virtual labs were average at best. Furthermore, the student stated that they believed that it “felt like work for the sake of doing work.” Similarly, Student #40 revealed that performing the virtual laboratory assignments did not require “very much understanding.”

In addition, students may not have understood where their data came from, whether this was in a virtual experiment or a different type of lab replacement exercise. For example, Student #46 indicated that they performed a virtual titration. They stated the following:

> I had such a hard time doing this because I had no idea how to get my chemicals to turn pink. Eventually, I got it to work, but I had no idea how to collect data from it or what it meant.

Student #45's Fractional Inquiry Score was 1.4, indicating that they had a high level of inquiry, yet their cognitive and affective scores were 43.8 and 0.00, respectively. This lack of understanding appears to have a severe, negative influence on students. The literature also shows students sometimes lack awareness of data sourcing. Dukes (2020) used recycled data, and students could not understand how the data was collected. Dukes (2020) went so far as to say:

> While the students completed a lab report with data from the instrument, and that lab report was graded, making the administration happy, the students that completed the assignment likely do not understand how to perform a separation with HPLC or an analysis with GC/MS as well as their predecessors who actually got time on the instruments (p. 2968).

This experience corresponds with those at El Camino College. Results of the qualitative survey showed that five students indicated they could not understand where the data came from, eleven were coded for believing the information they gathered in the lab held no meaning, and 25 could not relate what they were doing in the lab to their lecture material.

One item that cannot be discounted is the difficulties noted with the IRT at the beginning of this chapter. IRT values were higher than expected, possibly due to how students interpreted the inquiry questions. Reviewing student responses showed that often students regarded the questions to mean how thorough their instructors were, not the level of investigation students had to perform. A misinterpretation of the IRT questions could further contribute to the negative correlation between the MLLI and IRT values. Confusion likely led to lower MLLI scores because students felt left in the dark and forced to figure things out independently. It was also noted that the higher-than-expected inquiry scores could be related to similar factors. This combination may have increased the negative correlation between IRT and MLLI.

Research Question 3 Conclusions

Research Question 3 stated: was there a link between the level of inquiry and the level of meaningful learning experienced by students at El Camino College during ERT? Statistical testing showed a negative correlation between the perceived level of inquiry students at El Camino College experienced during ERT and their cognitive, affective, cognitive/affective, and overall meaningful learning scores determined by MLLI. The major contributing factors were confusion and a lack of understanding of what they were doing for the laboratory component of their chemical education.

Other factors contributed to this negative correlation. First, a lack of hands-on activities for all but four of the surveyed students added to these issues. Kelley (2021b), in a review of COVID-19 laboratory-based articles, stated that when students do not develop technical skills typically found in the lab, they may feel poorly about their experience. This aligns with Novak's (1998) meaningful learning overlap between the psychomotor, affective, and cognitive domains. Furthermore, while the materials given to students may have been meant to illicit an inquiry-based experience, they could have been boring or low-quality and did not engage students. In addition, students often did not understand the source of their data. Referring once more to Novak and his Human Constructivism (1993) theory, students construct their knowledge based on previous experience. Still, the materials must be attractive enough for them to want to incorporate them. The negative experience students had at El Camino College during ERT likely did not drive this wish to include it.

Research Question 4

Research Question 4 provided the basis for the other three. Still, it was placed last to act as an all-encompassing look at the experience that students had while in ERT at El Camino College regarding their online chemistry laboratory experience. There are no hypotheses to accompany this research question -- it was initially meant to review the phenomenological experience of El Camino students. Instead, the emergent quantitative data will look at the question holistically.

The final research question for this work was:

- RQ4: What was the phenomenological experience for students in ERT laboratory exercises at El Camino College?

The first item reviewed for this question was to determine if there was a difference between students who had more classes online compared to those who had fewer. Students reported between one to four semesters online, with one semester being the most common (n = 44). ANOVA tests were conducted between the semesters spent online and cognitive, affective, and the Fractional Inquiry Score. The ANOVA tests showed no significant difference between the different groups. The results indicates that students had similar experiences regardless of how long they spent online. Cognitive and Fractional Inquiry Scores fluctuated across the semesters, with no discernable pattern.

The mean affective score connected to semesters did decrease. The mean for one semester online was 35.74 (SD = 19.68), while the mean for four semesters online was 24.28 (SD = 14.18). While not significant enough using the alpha value of 0.05, a downward trend can be seen. The downward trend indicates that as students remained online, their affective values continued downwards. With a broader population sampling, this trend may have been significant.

From the quantitative and qualitative data collected so far, the experience students had at El Camino College with online chemistry laboratories was negative. It has been shown that affective, cognitive, and cognitive/affective scores using the MLLI were generally lower than those published in the literature, including comparisons with traditional labs, hybrid labs, and fully online ERT labs.

A deeper look into the quantitative data did help to elaborate on the experience students had. For example, as pointed out in the correlation between IRT and MLLI, students appeared to be confused about what they were doing and the meaning of their work. A review of the other questions shows a few other trends related to the overall experience.

Students continually felt frustrated (MLLI Q21 = 78.43) and intimidated (MLLI Q28 = 70.23). Qualitative questions further confirmed this. Frustration was a common theme under the Negative Experience code. For example, Student #8 stated, “It was quite frustrating most of the time, as it felt as though it took longer to grasp the concepts when you couldn't physically perform the lab.”

When reviewing the MLLI data, students generally did not feel any excitement about chemistry (MLLI Q8 = 44.84) and could not relate the chemical experience to their real lives (MLLI Q1 = 44.62). Qualitative experiences followed this trend as well. For example, Student #23 stated, “I would say that most of the labs I've done online are unenjoyable. It just felt like I had to go through the motions of completing the lab worksheet and felt like I never really learned anything.”

Some students did appear to realize that instructors were doing their best. While the overall experience from the quantitative paint a somewhat negative picture, it is essential to remember that instructors were also going through difficult times. As previously stated, instructors at El Camino were given free rein on how to approach their classes, and anything was considered “good enough.” Students echoed this understanding, with seven out of the 65 students who provided qualitative data coded as stating they understood their instructors were trying to give the best experience possible. For example, Student #6 said, “Overall, I think my professors did the best they could given the circumstances and were able to use the labs to give us a better understanding of topics in the class.”

Unfortunately, from the qualitative data, it seems that students had more negative interactions with their instructors than positive interactions. Out of the 65 students who provided qualitative data, only two students were coded as having positive experiences with their instructors. Student #54 stated their professor was very accommodating and was able to answer questions during group work. On the other hand, 16 students were coded as having negative experiences with their instructors. A lack of instructor presence was typical for this code. For example, Student #45 stated, “I had to deal with (technicalities) and I had no one to help me while doing the labs. Usually, I would email the professor, and I would not get a response until a day later."

On interpersonal activities, many students mentioned groups in their qualitative data. The use of breakout rooms has been noted in the chemical education literature. The idea of a breakout room is to bring the social aspect of education into the online environment. For example, Samson (2020) noted the use of breakout rooms was initially met with apprehension, but once students understood how to work in the groups, students became very participatory. Similarly, Nickerson and Shea (2020) used breakout room discussions and group work in a first-semester organic chemistry and had generally positive feedback from students. Yet, this isn't always the case. For example, Petillion and McNeil (2020) noted student dissatisfaction due to the way the breakout rooms were managed, indicating that there is an instructor component necessary to use this tool effectively

Similarly, students that took part in this survey had both experiences. Of the 65 students who relayed qualitative data, 14 were coded as having positive experiences with their groups. Flick (1995) noted one of the critical components of the laboratory was learning to work with groups. While not an entirely in-person and hands-on experience, it would seem that this type of work was essential to many students. For example, Student #10 stated:

> I don't think I thought much more of them than just being assignments but was (sic) really helped was being able to still work in groups. That was incredible, and 1000% (sic) contributed to me feeling like I was part of the class even more.

Not every experience noted by survey students with groups was positive. Out of the five students coded for having negative experiences with their groups, four pointed out that the communication in their groups was the issue. This leans towards the idea stated by

Petllion and McNeil (2020) that unregulated breakout rooms can lead to dissatisfaction. For example, Student #54 said:

> An unenjoyable experience was also group work as when your (sic) on zoom, no one is obligated to turn on their camera's or microphones meaning not everyone will always pay attention or try to collaborate. It felt especially evident when I asked a question to the group, but no one responded.

With low affective and cognitive scores, confusion, and frustration rampant, it appears that all of the experiences students had during ERT were poor. This is not the case. Some students had relatively high MLLI scores. It is worthy to note that 18 students out of the 65 coded for qualitative data were coded for reporting a positive experience while in ERT.

Some students enjoyed the ease and flexibility of the online environment. Out of the students who submitted qualitative data, seven were coded with Flexible, and nine were coded for Easy. For example, Student #11 stated, “I liked the flexibility of doing online experiments and how data was already given.”

The ease of use and the ability to focus on materials instead of making mistakes in the lab was noted by several students. When reviewing the MLLI data, the two questions with the highest contributing scores to the cognitive values were MLLI Questions #17 and #26. Question #17 stated “… ‘got stuck’ but kept trying,” while Question #26 said “…made mistakes and tried again.” The average scores for these two questions were 76.49 and 77.57, respectively—well above the average for the cognitive score. This highlights one of the positives of the online environment. One example qualitative statement that seems to encompass these ideals is Student #27:

> It was more enjoyable than in-person due to mainly (sic) it was less stressful, and I wasn't so focus on not making mistakes. I was able to focus more on concepts and the

> overall experience of the lab. Of course, online has it's (sic) own issues such as getting stuck and not having the professor right there. Also, it was confusing at times, but I did enjoy learning at my own pace and not rushed.

Similarly, student #52 recounted, “it's nice to be at the comfortable (sic) of your home and making mistake through online chemistry.”

The literature refers to students having higher affective outcomes when they performed hands-on activities in ERT (Kelley, 2021b). Only four students out of those who turned in qualitative data noted any type of hands-on. Even those who did seemed to have very few experiments where they were required to perform hands-on work. For example, Student #32 stated, “we mainly did worksheets and one project/lab that was done hands on at home.”

An ANOVA analysis was performed to see if there was a difference in IRT or MLLI scores compared to what techniques a student had for their online laboratory experience. Results for the test can be found in Chapter 4 in Table 32. As previously stated, the only test that showed a difference was based on the Fractional Inquiry Score compared to Virtual Labs and was the opposite of what was expected.

While there was no significance in the ANOVA analysis, many students stated they wished for a hands-on experience. Of the students who submitted qualitative data, 24 noted a lack of hands-on and the experiential difference they had. Of a special note, Student #31's response to the first qualitative question seems to encompass those who mentioned a lack of hands-on activities:

> My overall experience doing chemistry laboratory experiments while online felt like I was missing a large part of chemistry. I certainly missed the hands-on experience of an in-person lab. Getting to work in an environment that allows me to feel like I'm

doing the chemistry experiment myself is something that I have not been able to experience in an online setting.

Research Question #4 Summary

The experience students at El Camino College had during ERT lacked in several ways. The quantitative data has shown that students had a negative experience in the affective domain and experienced lower cognitive levels compared to the literature. Confusion and frustration were common amongst students.

Evaluations of the qualitative data cemented this idea. Student comments indicated that the online laboratory world was challenging for them. This isn't to say that every student had a negative experience. Some students mentioned the benefits of the online environment. The ability to work at their own pace was a typical positive students noted. The ability to try again with online materials without fear of spilling, losing the material, or being on a time crunch was supported both in the qualitative and quantitative work.

Yet there was something distinctly lacking. The American Chemical Society calls for hands-on chemistry experience (ACS Guidelines, 2015). For the most part, students at El Camino did not have this experience. This lack, coupled with instructor issues and low-quality materials, likely led to 19 students indicating in their qualitative questions that nothing was positive about their experience.

Study Conclusions

Hofstein and Lunetta (2003) noted some of the issues with laboratory classes in chemistry before the pandemic. They stated several items created poor learning environments in the lab: cookbook-style instruction, inadequate assessments of practical knowledge and ability, instructors not keeping up to date with suggested pedagogical literature, and lack of inquiry-based activities. It would appear that this was the experience for many students at El Camino College during ERT.

In this work, the IRT was discussed before the determination of the experience students had was completed. Some issues were noted. Correction of these problems may be possible by writing a more active series of questions. This allows students to interpret them based on what they were performing, not their feelings about the quality of their instructors. Removal of Inquiry Questions #1 and #2 would also be beneficial as students likely would not have this level of work at a community college level—students do not often devise their own experimentation and determine background information based on literature reviews at this level. The final aspect that would benefit the IRT is to combine Inquiry Questions #5 and #6 into a single question to separate Inquiry Level 0 and Level 0.5 instead of having two different components. These changes should eliminate most of the errors noted with the IRT and allow for a better evaluation of the perceived level of inquiry students experienced.

The four research questions were also reviewed. For Research Questions 1–3, hypotheses were developed. Reasons were then given for each of the corresponding results. Table 40 summarizes whether a particular hypothesis was held true and provides a brief description of why.

Table 40

Results for Research Questions 1–3, Corresponding Hypotheses and Brief Description of Why

Hypothesis	Held True	Why
Research Question 1 In terms of inquiry-based learning, what was the laboratory experience for students at El Camino College during ERT?		Most students experienced low levels of inquiry. Very few with hands-on. High levels of confusion. Poor quality materials.
H_{o1}: There is no difference between the level of inquiry students experienced during ERT at El Camino College.	Yes	
H_{a1}: There is a difference between the level of inquiry students experienced during ERT at El Camino College.	No	
Research Question 2 Is the overall level of meaningful learning experienced by students at El Camino College during ERT similar to published literature values?		Lack of meaningful learning. Affective domain lower than all literature reviewed. Cognitive and cognitive/affective usually lower than the literature reviewed. High-stress levels, frustration, confusion. Possibly ill-planned exercises, and asynchronous activities contribute. Students did enjoy the ability to try materials again.
H_{o2}: There is no statistical difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values.	No	
H_{b1}: There is a significant difference between the overall level of meaningful learning experienced in laboratory exercises at El Camino College during ERT compared to published literature values.	Yes	
Research Question 3 Was there a link between the level of inquiry and the level of meaningful learning experienced by students at El Camino College during ERT?		Unexpected. Poor activities may contribute. Instructors lack of communication. Students did not understand what they were doing or why they were doing exercises. Confusion contributing.
H_{o3}: There is no correlation between the level of inquiry reported by students and the overall level of meaningful learning experienced in laboratory exercises by El Camino College students during ERT.	No	
H_{c1}: There is a positive correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.	No	
H_{c2}: There is a negative correlation between the level of inquiry reported by students and their overall level of meaningful learning in laboratory exercises at El Camino College during ERT.	Yes	

Regarding Research Question 1, students at El Camino College were found to have experienced similar levels of inquiry, all of it skewed towards lower levels. The majority of activities selected by instructors were commonly worksheets and watching videos. These types of instruments are generally low inquiry. While not statistically relevant due to a low n-value, the hands-on activity students had a higher mean Fractional Inquiry Score. Hands-on activities would have a higher level of inquiry and better at keeping in line with guidelines set by the ACS, yet few students were given this type of assignment.

Often students with higher inquiry scores indicated so because they were frustrated and confused about the laboratory materials. Scores may also have been higher due to misunderstanding the inquiry-based questions. Even with interactive demos, some students complained about not understanding the materials and felt frustrated by the experience. Virtual laboratory exercises should have had higher levels of inquiry due to their ability to replicate unknowns and allow students to develop hypotheses. Yet, Fractional Inquiry Scores were lower for students who may have viewed the virtual labs as simplistic and had difficulty relating the material to their lecture work.

For Research Question 2, it was determined that students at El Camino College mainly experienced lower affective, cognitive, and cognitive/affective scores than those in the literature. Three different literature selections were made—a full in-person setup, a hybrid setup, and an ERT setup. Compared to all three sources, affective scores for El Camino students were lower. The cognitive and cognitive/affective scores, when compared to one of the class values determined by Galloway and Bretz (2015a), were not significantly different. This was due to students in the current study recording high scores for items relating to the ability to redo materials that they did poorly the first time.

The rest of the cognitive and cognitive/affective scores were lower than those reported in the literature. A significant contributor to these lower scores was the materials selected by instructors and their implementation. The studies used for comparison were well planned out and had hands-on components, contributing to the difference in MLLI scores. High levels of confusion and frustration were standard in the current study. In addition, the use of synchronous materials appears to be an influencing factor. One positive determination from the MLLI quantitative data was that students could try materials repeatedly if they failed in the online world. Overall, students at El Camino College experienced lower levels of meaningful learning than those selected for comparison in this study.

Research Question 3 looked to determine if there was a link between the levels of inquiry students experienced and scores in the MLLI portion of the survey. A link was determined, but it was the opposite of what was expected. Literature has shown that when students work with inquiry over rote memorization, they generally have a more positive attitude (Abraham, 2011; Blanchard et al., 2010; Cacciatore & Sevian, 2009; Deters, 2005; Hall & McCurdy, 1990; Leonward, 1983). Yet, cognitive, affective, and cognitive/affective scores decreased as the level of inquiry increased.

A portion of the negative correlation is related to discrepancies with the IRT. In the earlier part of this chapter, it was noted that some students perceived IRT questions as relating to how well informed their instructors kept them. Inaccuracies in perceived IRT question meaning would artificially inflate the IRT score. Yet, there were more reasons for this negative correlation determined.

Once again, the confusion, frustration, and lack of understanding associated with the materials chosen impacted students. This lack of understanding appeared in the qualitative data, with students unable to determine the source of their data. They also could not relate their work to the lecture and felt that the lab replacement exercises had no meaning. Levels of confusion and frustration were also high in the MLLI scores. Students likely felt left in the dark and unable to comprehend why they were not told aspects of the laboratory exercises as instructors attempted to increase the level of inquiry in their experiment replacements.

Research Question 4 was meant as an all-encompassing review of the experience for students during ERT at El Camino College. While not every experience was negative, a large majority of them were. On average, students coded over double the number of negative codes than positive ones (2.78 vs. 1.16). Student frustrations were high, as were levels of confusion. Many students indicated that they did not have any good experience at all. Sixteen of the 64 students who gave qualitative data showed poor experiences with their instructors. Lack of communication and availability of instructors was common.

Some positives noted were the ability to work at their own pace and the flexibility associated with this. In addition, the ability to repeat experiments that might not have been possible face-to-face was annotated in the qualitative work and the MLLI portion of the survey. Many students noted positive group experiences. Of the 64 students with qualitative data, 24 emphasized the lack of hands-on or its effect. Once more, the desire for hands-on activities became an essential feature of note.

Conclusions Summary

The framework selected for this work was Novak's Theory of Human Constructivism (1993). Two components were chosen as focal points for this work. The first incorporates Ausubel's (1963, 1968) assimilation theory, in that students must have prior relatable knowledge, the new material must be meaningful, and the student must choose to incorporate the knowledge. Based on students' experiences at El Camino College during ERT, materials were not presented in such a way that students decided to incorporate them. Levels of frustration and confusion were high amongst students. There was a lack of understanding amongst students relating to what they were doing for their laboratory assignments. Due to this, it is unlikely that students will retain much knowledge from their experiences during ERT.

The second component of Novak's work that was important to the framework of this dissertation was the idea of meaningful learning (1998). Novak (1998) stated that meaningful learning is an overlap of the affective, cognitive, and psychomotor domains. In this work, it was determined that the psychomotor domain was not effectively engaged. Only four students reported the use of hands-on activities. Furthermore, students were engaged significantly less than in the selected literature pieces. This includes one work that was also in ERT, and yet, the scores using the MLLI were significantly lower at El Camino.

Concerning this framework, it was determined that, on average, students at El Camino College did not obtain meaningful learning from their online laboratory experiences. This isn't to say that the experience students had was without value. Battino (1992) and Novak (1998) indicate that rote learning in its many forms may be helpful as a platform for meaningful learning. Yet there was a definitive lack of students. Work given to students was low inquiry, likely cookbook-style work. Instructors did not follow pedagogical suggestions current in the literature. These things were warned against by Hofstein and Lunetta (2003). To ensure this is remedied and to prevent a lack of meaningful learning in the event of ERT in the future, the following section looks at the implications of this work and its importance to chemical education.

Implications for Practice and Scholarship

For this work, there were two different goals. The first was to test a new tool, the IRT, which was to be used to determine the perceived level of inquiry a student experienced when a traditional rubric could not be used. The second was to determine what experience students had at El Camino College. This section will discuss the IRT implications and student experience separately.

Inquiry Rubric Tool Implications

The IRT was developed to evaluate the widely varied experience students had in terms of inquiry during ERT at El Camino. Students had different instructors over several semesters. Each instructor had a pedagogical purview to teach as they saw fit. Therefore, the experience students had may have varied wildly. This means that a typical rubric, like Buck et al. (2008), could not have been applied. To use Buck et al.'s (2008) rubric, each experiment must be evaluated separately and scored individually.

This is where the IRT shines. It does not require any individual assessment. Instead, the IRT determines the perceived level of inquiry experienced by students. With only a few questions and the ability to determine perceived inquiry, the IRT allows for testing in a wide variety of surveys, particularly as an addon to other tools. For example, similar to this study, the IRT could be added to the MLLI and sent to several schools in a geographical location. Inquiry levels could not be compared between these schools without the IRT as a researcher would have to look at each student's class, the year, the instructor, and what experiments would be done. The IRT allows for a larger-scale survey instead of reviewing individual experiments.

Before this can be done, the IRT needs further testing. As noted earlier in this chapter, some errors are associated with the results. To combat this, questions must first be rewritten. Adding a more active role and a better description of the questions should reduce errors. In addition, the creation of an additional level of inquiry or combination of Inquiry Questions #5 and #6 may be of benefit. Finally, removing Inquiry Questions #1 and #2 may be beneficial in systems where actual research isn't conducted, such as a community college.

Once these changes are completed, the IRT will need to undergo further validation. Implementation of this will be discussed in the recommendation section of this chapter. Overall, the IRT may be a valuable tool with further testing and provide instructors a quick way to determine the level of inquiry students are experiencing.

Survey Result Implications

On average, students at El Camino College did not experience meaningful learning during ERT. Understanding this experience is vital for the college and the chemical education community. Dissemination of information based on the results of this study to El

Camino will allow for policy change to ensure better instruction happens in the event of an ERT event. In addition, it should help establish guidelines for creating hybrid and online chemistry curricula. Finally, information derived from this study may help answer the call that Hofstein and Lunetta (1982, 2003), as well as Bretz (2019), made to evaluate the importance of laboratory experimentation in chemistry.

Replacement exercises for El Camino students differed based on the class, semester, and who instructed them. Instructors at El Camino were free to do as they pleased with the laboratory portion of their classes, and anything was seen as “good enough.” Many students indicated issues with their instructors and the materials; therefore, this mentality was inappropriate given these results.

Many instructors likely attempted to replicate their in-person instruction. In the qualitative survey, some students indicated their instructors gave them worksheets that would typically be used in the lab. Students were then either given data or watched a video to collect it. The approach of non-student-generated data likely contributed to student difficulties.

Hodges et al. (2020) noted a distinct difference between ERT and actual hybrid learning. If a class is to be moved to a hybrid or online format, the techniques used during ERT should not simply be moved over. Instead, lessons learned in this research would be beneficial. The inclusion of hands-on activities is essential. Synchronous activities are vital as well. Using robust and functional virtual experimentation would also be helpful. Constant communication between students and faculty members with faculty ensuring they follow current pedagogical guidelines is also essential.

These ideals may be applied to hybrid or partially online chemistry courses at El Camino. Another component is developing an ERT plan in case the situation happens again. For either situation, a series of experiments and guidelines should be created and faculty instructed in their use. This way, it ensures that students receive the same education backed by the data represented in this work and the literature. Meaningful learning can be maximized for students when in one of these environments.

In addition, disseminating this information to instructors is beneficial for current pedagogical changes during in-person experiences. Changes such as these have been noted in the literature (George-Williams et al., 2020; Kelley, 2021a; Schweiker & Levonis, 2020; Wilson, 2020). Results from this study have shown that students may benefit from more flexibility in the laboratory, and group work is essential. Instructors must be present as they make a difference in a student's experience. Finally, seeing where failures occurred online is beneficial to increasing inquiry in the face-to-face classroom to increase student outcomes.

The implications of this survey are also of benefit to the chemistry education community. As stated, Hofstein and Lunetta (1983, 2003) and Bretz (2019) called for chemistry instructors to defend the importance of their laboratory work. Results from this work showed that meaningful learning suffered when there was a lack of hands-on or inquiry-driven activities. As instructors return to in-person activities at El Camino College, they will likely see students suffering due to the lack of beneficial experience during ERT. This information is vital to the scientific community as it helps establish that the laboratory is still an essential component of education.

It also helps solidify the importance of staying up to date on pedagogical guidelines. The work done in ERT did not match current literature guidelines. There was very little inquiry involved in experimentation. Techniques such as MORE (Tien et al., 2007) and Argument-Driven Inquiry (Walker et al., 2011) were not used. A definitive lack of inquiry has been noted as typical in the sciences (National Research Council, 1996). Reporting this lack's effects on students can help ensure that others do not make similar choices.

The information in this work is essential for El Camino College and the chemistry education community. It may help to drive policy changes at El Camino. Too often, due to funding formulas, the administration attempts to fill in as many seats as possible. Larger numbers are easily reachable with hybrid and online courses as they are not limited to physical locations and schedules. Demonstrating that students are not achieving meaningful learning in this type of environment can ensure that these policy changes do not occur without the backing of scientific data and faculty support. It also helps show the larger community that hands-on activities are essential and should continue to be a part of the chemical education curriculum. It also demonstrates that changes may need to be made to include higher levels of inquiry to help ensure students receive the best education possible.

Study Limitations

This study focused on a single institution of higher education—El Camino College. The single location limits the number of survey takers and their experiences. In addition, while the study's goal was to obtain at least 30 usable data points from the survey, the response rate was relatively low. Few students had hands-on laboratories, so the full effect this type of online learning would have on a student could not be fully realized. Higher response rates with a more extensive experience sampling would have been preferable.

Future Research

The expanded use of the IRT is the next step in future research, though it still requires further testing. After survey questions have been rewritten and a decision made on whether to add another level of inquiry or combine Inquiry Questions #5 and #6, the IRT will need to be retested. Now that classes have restarted at El Camino, determining what experiments are being conducted is much easier. The IRT can be given to instructors immediately following a particular lab, and their perceived level of inquiry can be tested against an experiment's known level of inquiry using the Buck et al. (2008) rubric.

Once further validation is complete, the IRT can be submitted to a student body again, accompanied by the MLLI. Often, the MLLI is given in a pre- and post-semester format, as described throughout this work. The MLLI and IRT survey can be given together to students in both these formats and tracked to see their expected level of inquiry vs. the level they perceived at the end of the semester. MLLI testing on its own in a pre- and post-semester setup is also beneficial to compare to the data of this work to determine if student attitudes change once returning to in-person and hands-on instruction.

Finally, after validation and publication, the IRT and MLLI can be given to a larger group, such as across Southern California Community Colleges. The ease of use of the two tests together allows for rapid testing and large-scale data collection. These two tools can make understanding the link between inquiry and meaningful learning easier.

Closing Comments

The results from this study are not surprising to me. As an instructor who had to shift to online instruction at El Camino College rapidly, I had firsthand experience. I felt the difficulties instructors had as well as monitoring the experience of my students. I started asynchronously, attempting to work with student lives as easily as possible, but when I noticed low learning outcomes, I switched to synchronous work. Student outcomes improved somewhat, but overall, a malaise seemed to permeate amongst students.

This is why the results here are so important. As scientists and instructors, we should be open to the idea that what we believe is best may be wrong. We must accept facts when presented to us. This work has shown what many fellow faculty members have voiced: meaningful learning did not occur. When presented with such data, it's imperative to shift the paradigm to prevent it from happening again.

I understand that all instructors did their best during ERT, which was a terrible experience. But as we move into the future, we need to be ready in case such an event happens again. We must understand what happened when we did not work as a single unit with literature-backed ideals. As we move into the future, we also need to keep this work in mind, as the pandemic has shown that online learning may be feasible in some cases. Online learning may very well be the way of the future. To ensure that students receive the best education possible in such an environment, work like this is essential to understand best practices and what fails to influence meaningful learning.

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APPENDIX A: SURVEY EMAILS

Instructor Survey:

Hello, fellow chemistry instructors!

I'm using the most recent email list from Amy for our full time and part time instructors at El Camino. For those of you who don't know me, my name is Shaun Cook. I am a full-time instructor here at El Camino. Currently, I am attending Pepperdine University for my doctorate, focusing on learning technologies. As we come back to campus, a unique opportunity presents itself.

El Camino College has been in Emergency Remote Teaching (ERT) for two years. That's eight semesters! We have students who have experienced something like never before – chemistry without a lab. There was no solid guidance at El Camino, and instructors were told to do their best to replace laboratory experiences. We all did different things to bring our students the best education possible.

What experience did these students have? Was it meaningful? Did they have any say in the experience? Was there a correlation between what we did and their experiences? These are the types of questions I'm looking into as I move into my dissertation.

There are two parts to my work. I hope to receive help from all of you in discovering what happened with our students during these unprecedented times. In this first part, I need your help validating a tool I created – the Inquiry Rubric Tool. The tool was developed from an individual experiment rubric tool designed by Buck, Bretz, and Towns (2008). The goal of the tool is to see what level of inquiry students perceived they had during ERT.

I need as many of you as possible to take the survey to aid in validating the tool. It's relatively simple, should only take 5-10 minutes. Your responses are anonymous.

I would like this data to be compiled as quickly as possible, so I would like to end the survey by April 4th, 2022.

The survey link is: https://pepperdine.qualtrics.com/jfe/form/SV_54Mk9MmXFRRsUvQ

Your assistance in this matter is greatly appreciated! Thank you so much for your time!

This is also the first time I've used the Qualtrics program, so if you have any issues, please let me know ASAP! Thank you!

Shaun Cook

Student Survey:

Hello all,

This is the third of four emails I'll be sending. If you haven't filled out the survey based on your experience teaching online laboratory courses, please refer back to my previous email and do so! It would be a great help to me!

I have moved to my dissertation project's second portion of my data collection! I need your help once again! This time the student survey is for your students!

I need as many students as possible to take the survey this time. If you can, please send out an email/make an announcement in Canvas to your students (past or present) to take the survey. If you are willing to offer extra credit for students who will take the survey, I will be collecting their names after the completed surveys. Their current instructor will also be a part of the survey. There is no link between the name submission and the actual survey, so their data is completely safe and anonymous. After the survey period, I will send individual instructors a list of student name who took the survey.

If you want to see the study, you can click on the Qualtrics link, but do not take it. The study is geared to the student experience.

Below are two different guiding emails to simplify things for you. They should be cut-and-paste ready.

If you are willing to offer extra credit to your students, use the following email/announcement:

Hello students!

Professor Shaun Cook, one of the chemistry instructors at El Camino College, needs your help. He is conducting research to understand the experience students had while the school was in an Emergency Remote Teaching situation due to the COVID-19 pandemic. Typically, students who take chemistry have a hands-on experience. Many of you took chemistry classes here at El Camino, where this was impossible. He would like to know what your experience was like!

Some notes about the survey:

The survey is completely voluntary. Participation or lack thereof will not affect your grade in anyway.

It is entirely anonymous. Data submitted to the survey can not be tracked back to an individual.

The survey should take about 20-40 minutes.

All data is held on encrypted sites. Information is stored on an encrypted and password-protected drive when removed from the site for computation.

There is a portion where you may write openly about your experience. Please be as honest as possible!

After the survey, there is an opportunity to provide your name and your instructor. Find my name and click on the checkbox. Your name will be sent to me after the completion of the study. Your name will not be connected to the data you submit in any way. The only reason for this is to allow me to know who completed the survey for extra credit purposes.

Findings from this research will have several implications. Some of it may be published in peer-reviewed journals so that others understand the experience community college students had during these unprecedented times. Findings will also be discussed with chemistry instructors at El Camino to help understand how we can better serve our student population. This is an opportunity for you to act as an agent of change by increasing our knowledge!

The link for the survey is: https://pepperdine.qualtrics.com/jfe/form/SV_8pQU4610xrDiHvU

The completion of the study will be: April 10th, 2022. Please complete the survey by then.

Thank you for your time and effort! Your voice is vital to furthering our understanding!

If you do not wish to offer extra credit for students to take the survey, use the email/announcement below. It has had #6 from the above removed.

Hello students!

Professor Shaun Cook, one of the chemistry instructors at El Camino College, needs your help. He is conducting research to understand the experience students had while the school was in an Emergency Remote Teaching situation due to the COVID-19 pandemic. Typically, students who take chemistry have a hands-on experience. Many of you took chemistry classes here at El Camino, where this was impossible. He would like to know what your experience was like!

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All data is held on encrypted sites. Information is stored on an encrypted and password-protected drive when removed from the site for computation.

There is a portion where you may write openly about your experience. Please be as honest as possible!

Findings from this research will have several implications. Some of it may be published in peer-reviewed journals so that others understand the experience community college students had during these unprecedented times. Findings will also be discussed with chemistry instructors at El Camino to help understand how we can better serve our student population. This is an opportunity for you to act as an agent of change by increasing our knowledge!

The link for the survey is: https://pepperdine.qualtrics.com/jfe/form/SV_8pQU4610xrDiHvU

The completion of the study will be: April 10th, 2022. Please complete the survey by then.

Thank you for your time and effort! Your voice is vital to furthering our understanding!

Your efforts are incredibly helpful here. I know all of us are busy as we return to in-person instruction. You are not only helping me complete my doctorate but helping to further our understanding of the student experience.

Thank you!
Shaun Cook

APPENDIX B: INSTRUCTOR ONLY SURVEY

How many semesters did you give assignments related to laboratory courses while online? __

The questions below are rated between 0% meaning *Never* and 100% meaning *Always*. Examples are given for each question for 0% and 100%. Move the slider to the appropriate value related to your overall online laboratory experience for each question.

	Question	0% Example	100% Example
Q1	How often did you give the purpose and ultimate task of the lab to the students?	Students always had to come up with an experiment on their own. They decided what technique and experiment they would perform.	Students were always given questions to answer for the lab. They were told what they were doing through lab procedures or lectures.
Q2	How often did you provide the background knowledge for experiments?	Students had to look up how the experiment is performed and what theory is involved. They had to look through the literature to determine this.	Students were provided with some type of background information. They may have been in their book or in the lab procedure.
Q3	How often did you give the procedures/directions to students for their experiments?	Students were told what needed to be investigated but had to research a proper procedure or come up with one on their own.	Students were always given a list of procedures and steps to perform the lab, whether dry, virtual, or wet.
Q4	How often did you inform students how to interpret the experimental results once data was collected?	Students had to figure out how to interpret the results on their own. There was no guidance given in the procedure.	Students were given a series of steps to perform calculations. They were told what to do to figure out what the results meant.
Q5	How often did you tell students how to communicate the experiment results?	Students came up with a series of results and had to figure out precisely what it meant and how to communicate them.	Students were given problems/questions to answer based on their results.
Q6	Before beginning an experiment, how often did students know the expected answer?	Student work had an unknown component to it.	Students knew they were supposed to get a specific value from their calculations.

APPENDIX C: FULL STUDENT SURVEY

Section I – Introduction

Q1. Did you take any chemistry courses at El Camino College that had an online chemistry component (This can include any assessment your instructor identified as a lab) – Y/N

Q2. How many semesters did you take chemistry courses online at El Camino College that had defined laboratory components? __

Section II – Inquiry Rubric Tool

In this section, questions are related to what you were provided in laboratory assignments and what you had to do independently. These questions are not concerning any singular laboratory assignment or a specific class. They involve your entire experience. Think of it as an overall experience while you did laboratory work online.

These questions relate to laboratory-based assignments only.

The questions below are rated between 0% meaning *Never* and 100% meaning A*lways*. Examples are given for each question for 0% and 100%. Move the slider to the appropriate value related to your overall online laboratory experience.

	Question	0% Example	100% Example
Q1	How often were the purpose and ultimate task of the lab given to you?	You always had to come up with an experiment on your own. You decided what technique and experiment you would perform.	You were always given questions to answer for the lab. You were told what you were doing through lab procedure or lecture.
Q2	How often was the background knowledge described for experiments?	You had to look up how the experiment is performed and what theory is involved. You had to look through the literature to determine this.	You were provided with some type of background information. This may have been in your book or on the lab procedure.
Q3	How often were the procedures/directions given to you during experiments?	You were told what needed to be investigated but had to research a proper procedure or come up with one on your own.	You were always given a list of procedures and steps to perform the lab, whether dry, virtual, or wet.
Q4	How often were you told how to interpret the experimental results once data was collected?	You had to figure out how to interpret the results on your own. There was no guidance given in the procedure.	You were given a series of steps to perform calculations. You were told what to do to figure out what the results meant.

Q5	How often were you told how to communicate the results of the experiment?	You came up with a series of results and had to figure out precisely what it meant and how to communicate them.	You were given problems/questions to answer based on your results.
Q6	Before beginning an experiment, how often did you know the expected answer?	Your work had an unknown component to it.	You knew you were supposed to get a specific value from your calculations.

Section III – MLLI

Like the above section, think about your overall laboratory experience while online. Each question is related to the initial prompt. Rate your overall experience in relation to the question between 0%, *Completely Disagree*, and 100%, *Completely Agree*. Be careful of the wording!

For example, question 3 should be ‘While performing chemistry laboratory experiments in an online environment, I made decisions about what data to collect.’ You would rate your experience between 0% (*Completely Disagree*) to 100% (*Completely Agree*) on how often you made decisions on what data to collect.

While performing chemistry laboratory experiments in an online environment, I…
Q1. Learned chemistry that will be useful in my life.
Q2. Worried about finishing on time.
Q3. Made decisions about what data to collect.
Q4. Felt unsure about the purpose of the procedures.
Q5. Experienced moments of insight.
Q6. Was confused about how the instruments/programs work.
Q7. Learned critical thinking skills.
Q8. Was excited to do chemistry.
Q9. Was nervous about making mistakes.
Q10. Considered if my data makes sense.
Q11. Thought about what the molecules are doing.
Q12. Felt disorganized.
Q13. Developed confidence in the laboratory.
Q14. Worried about getting good data.
Q15. Thought the procedures to be simple to do.
Q16. Was confused about underlying concepts.
Q17. “got stuck” but kept trying.
Q18. Was nervous about employing the program or performing experiments at home when applicable.
Q19. Thought about chemistry I already know.
Q20. Worried about the quality of my data.
Q21. Was frustrated.
Q22. Interpreted my data beyond only doing calculations.
Q23. TEST STATEMENT: Please select 60 percent for this question.
Q24. Focused on procedures, not concepts.
Q25. Used my observations to understand the behavior of atoms and molecules.
Q26. Made mistakes and tried again.

Q27. Was intrigued by the instruments/programs used for laboratory assignments.
Q28. Felt intimidated.
Q29. Was confused about what my data meant.
Q30. Was confident when using equipment/programs.
Q31. Learned problem-solving skills.

Section IV – Open-Ended Questions

Here is your chance, in your own words, to talk about your experience while doing chemistry laboratory experiments online! You may answer the question however you wish. As a reminder, your answers will not be shared with any identification attached. The goal is to build on understanding student experiences while online and possibly make policy changes to serve the student population better!

Q1. Describe your overall experience doing chemistry laboratory experiments while online.
Q2. What types of experiments did the instructor(s) give you to do (e.g., worksheets, interactive demos, take-home kitchen labs, etc.)? What were your thoughts on them?
Q3. Describe an enjoyable experience you had during online chemistry experimentation.
Q4. Describe an unenjoyable experience you had during online chemistry experimentation.
Q5. How much input did you have on what experiments were conducted and how they were conducted? Tell about the experience.

APPENDIX D: CODEBOOK

The following codebook was shared between the coders for the purpose of this study.

Feelings			
Code	Title	Description	Additional/Trigger Wording
N1	Negative Experiences	Used when the student relates a negative experience or feeling. This could range from frustration to boredom.	Frustrated, mad, bored, angry, hate
P1	Positive Experiences	Used when student relates a positive experience. This could be having fun with an experiment, enjoying something in particular, being happy about something.	Fun, interesting, intriguing, exciting
HO1	Desire for Hands On	Used when the student explicitely states that they wanted something hands on or done in person.	
CV1	Covid Understanding	Students understood that instructors were doing their best attempting to comepnsate for the pandemic	Doing their best, better than nothing

Community Experience			
Code	Title	Description	Additional/Trigger Wording
I1	Issues with Instructor	Used when there was something negative stated about their instructor. This can be lack of an instructor presence, instructor slow to respond, or that their instructor was not there for them.	
PI1	Positive Instructor Influence	This code is used when a student states that their instructor had a positive influence on them. This could be that they enjoyed something the instructor did, or that they felt like the instructor was there to support them.	
GP1	Positive Group Member Experience	Coded when a person states that they had a positive experience working with other students.	

GN1	Negative Group Member Experience	Coded when a person states that they have a negative experience when working with groups of students	

Types of Instruction			
Code	Title	Description	Additional/Trigger Wording
TO1	Watching Instructor	This is used when a student explicately states that they watched THEIR instructor perform an experiment, whether live or via video.	
V1	Videos	Coded when students watched videos as part of their lab experience.	Youtube, watched a video of, gave us movies
DA1	Data Computation	When only data was given to a student to perform calculations or data was filled in for them.	
WK1	Worksheets	When worksheets were used in place of a lab.	
LP1	Predictions (Removed)	When a student was forced to make predictions based on lecture knowledge and no experiment was performed	Make predictions, just fill in data without source
AE1	Actual Experimentation	Students performed something hands on at home	Kitchen lab, hands on lab, actually did experiment
IL1	Interactive Labs	When a virtual lab, program or something interactive the student could use was done in place of a lab	Virtual lab, interactive lab, interactive experience, computer program

Experience			
Code	Title	Description	Additional/Trigger Wording
F1	Flexible	Coded when a student states that they liked the fact that they could do things in their own time, on their own or that the scheduling for labs was flexible.	
E1	Easy	When a student says that the labs were easy, but not to be confused with ease of use. This is used when the student describes the work behind the lab was simplistic/easy to accomplish.	Simple, easy, wasn't hard
RP1	Relating/Relevance Understanding	When a student is able to relate what they are doing in lab to lecture or future work. This also is used when a student states that it was helpful in their education.	Understood why we did it, related well back to lecture, helped understanding
R1	Relating/Relevance Issues	Coded when a students state they were unable to relate the things they did in lab with their lecture. They were unsure of its relavence. They did not understand why they were doing the work. This does not include when students do not understand where data comes from.	Couldn't relate to lecture, didn't see why its useful, don't know why we did it
C1	Confusing	Coded when a student was confused by something or didn't understand what they were doing.	Confusing, hard to understand, didn't get it
TI1	Time Issues	Coded when a student expresses that they had issues with time. This could be that the course is too fast, they felt rushed, etc.	
D1	Difficult	When a student specifically states they thought the labs were difficult	Hard, difficult, wasn't easy

Material Experience			
Code	Title	Description	Additional/Trigger Wording
EV1	Enjoyed Visuals	Used when students expressed a positive feeling about visuals they saw, whether it was an instructor, visualization of a lab, or similar.	
EU1	Ease of Use	Materials were using to use, didn't have to do much to get things, didn't have to worry about messing up an experiment on their own.	
DC1	Not Understanding Data	Used when students do not understand where data came from, how its used, or its importance to what they are learning	
NE1	No Good Experience	Used when students explicetly express no positive experience while performing lab experimentation online	
LQ1	Low Quality Materials	Used when students state that videos they were watching were low quality, difficulty seeing things, or the programs they were using didn't work well	Couldn't see because of video, program didn't work

Input In Lab			
Code	Title	Description	Additional/Trigger Wording
IN0	No Input	Used when students express that they did not have any input, or use phrases such as 'almost nothing' or 'next to nothing' or 'slim to none)	
IN1	Some Input	When students explicetly state that they had some input on the work happening in lab.	
IN2	Lots of Input	When students state that they were able to have a lot of input in what was happening in lab.	

APPENDIX E: INFORMED CONSENT

IRB Number #22-02-1760
Study Title:
The Chemistry Laboratory Experience of El Camino Students While in Emergency Remote Teaching Due to the COVID-19 Pandemic

Invitation

Greetings and welcome!

My name is Shaun A Cook. I am conducting a study on the experience students had at El Camino College during the movement to online earning, forced by the COVID-19 pandemic. The study focuses on the chemistry laboratory. If you are 18 years of age or older and are a student or instructor at El Camino College, you may participate in this research.

Thank you for taking the time to do this survey! Your responses are important! Please think through the questions carefully when answering them. All questions are concerning your experience while taking online chemistry courses.

What is the reason for doing this research study?

The purpose of this study is to understand the experience El Camino students had during the COVID-19 pandemic in relationship to online chemistry laboratory work. You will be asked a series of questions to relate your experience from 0% (*Never*) to 100% (a*lways*) for Section II and from 0% (*Completely Disagree*) to 100% (*Completely Agree*) in Section III. Finally, in Section IV, you will also be asked some open-ended questions. Answer to your best ability!

What will be done during this research study?

This survey should take approximately 20-40 minutes to complete. The survey should be taken outside of class. Completion of the survey or refusal to do so will not affect your grade in anyway. You may stop at any point or leave answers blank if you do not feel comfortable. Upon successful completion of the survey, you will be given a link to submit your name and current instructor. Only completed surveys will have their name sent to current instructors. This will be done so that instructors may provide extra credit if they so wish, but this is not guaranteed by taking the survey. Instructors make their own decisions on what extra credit, if any, they will give. Data collection will take place for approximately two weeks, at which point the survey will close, and instructors will be informed which students took the survey.

What are the possible risks of being in this research study?

Risks for taking part in this survey are minimal. There is a chance for the data to become compromised, but how the data is collected and stored is meant to maximize anonymity and security as detailed below.

Please note that the questions in this survey relate to your experience during the COVID-19 pandemic. If bringing up any memories from the pandemic impact your mental health, please reach out to the Student Health Services. Their website is: https://www.elcamino.edu/support/health-safety/student-health-services/index.as and can be reached at 310-660-3643.

What are the possible benefits to you?

The results of this study will be used to understand the experiences students had during COVID-19 at El Camino College. This information is vital to improving pedagogy amongst instructors and to build better laboratory experiences now and in case of another emergency remote teaching event. Your answers will help aid in this and may improve your college experience in future classes.

How will information about you be protected?

Your privacy is critical. After successful completion of the survey, you will be provided with a link that will take you to a Google Forms where you will be asked for your name and current student instructor. No data will be linked to this name. Data collection and name collection is done on completely separate sites, so there is no chance for your data to be tied to your person. Your answers will be stored online on the encrypted Qualtrics site and your name on an encrypted Google Form. Data will be encrypted and password protected on a backup drive where only the primary investigator will have access for up to three years. Your name will be deleted from the Google Survey at the completion of the study. While there is always a chance for data to be stolen in the modern age, the risks to you are minimal. So answer truthfully, whether the experience was good or bad! It's vital to make instructional changes to receive the best instruction possible for El Camino students!

What are your rights as a research subject?

You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study.

For study related questions, please contact the investigator: Shaun A Cook
scook@elcamino.edu

For questions concerning your rights or complaints about the research contact Pepperdine Institutional Review Board (IRB):

Phone: 1(310)568-2305
Email: gpsirb@pepperdine.edu

In addition, if you have any further questions or concerns about taking this survey, you may contact the El Camino College Instructional Review Board.

Website: https://www.elcamino.edu/about/institutional-research/conducting-research.aspx. Phone: 310-660-3593, ext. 3150.

What will happen if you decide not to be in this research study or decide to stop participating once you start?

You can decide not to be in this research study, or you can stop being in this research study (“withdraw’) at any time before, during, or after the research begins for any reason. Deciding not to be in this research study or deciding to withdraw will not affect your relationship with the investigator or with Pepperdine University (list others as applicable).

You will not lose any benefits to which you are entitled.

Documentation of Informed Consent

You are voluntarily making a decision whether or not to participate in this research study. By clicking on the I Agree button below, your consent to participate is implied. In addition, by clicking I Agree, you indicate that you are 18 years or older. You should print a copy of this page for your records.

I agree

I do not agree

APPENDIX F: IRB APPROVAL

Pepperdine University
24255 Pacific Coast Highway
Malibu, CA 90263
TEL: 310-506-4000

NOTICE OF APPROVAL FOR HUMAN RESEARCH

Date: March 22, 2022

Protocol Investigator Name: Shaun Cook

Protocol #: 22-02-1760

Project Title: The Chemistry Laboratory Experience of El Camino Students While in Emergency Remote Teaching Due to the COVID-19 Pandemic

School: Graduate School of Education and Psychology

Dear Shaun Cook:

Thank you for submitting your application for exempt review to Pepperdine University's Institutional Review Board (IRB). We appreciate the work you have done on your proposal. The IRB has reviewed your submitted IRB application and all ancillary materials. Upon review, the IRB has determined that the above entitled project meets the requirements for exemption under the federal regulations 45 CFR 46.101 that govern the protections of human subjects.

Your research must be conducted according to the proposal that was submitted to the IRB. If changes to the approved protocol occur, a revised protocol must be reviewed and approved by the IRB before implementation. For any proposed changes in your research protocol, please submit an amendment to the IRB. Since your study falls under exemption, there is no requirement for continuing IRB review of your project. Please be aware that changes to your protocol may prevent the research from qualifying for exemption from 45 CFR 46.101 and require submission of a new IRB application or other materials to the IRB.

A goal of the IRB is to prevent negative occurrences during any research study. However, despite the best intent, unforeseen circumstances or events may arise during the research. If an unexpected situation or adverse event happens during your investigation, please notify the IRB as soon as possible. We will ask for a complete written explanation of the event and your written response. Other actions also may be required depending on the nature of the event. Details regarding the timeframe in which adverse events must be reported to the IRB and documenting the adverse event can be found in the *Pepperdine University Protection of Human Participants in Research: Policies and Procedures Manual* at community.pepperdine.edu/irb.

Please refer to the protocol number denoted above in all communication or correspondence related to your application and this approval. Should you have additional questions or require clarification of the contents of this letter, please contact the IRB Office. On behalf of the IRB, I wish you success in this scholarly pursuit.

Sincerely,

Judy Ho, Ph.D., IRB Chair

cc: Mrs. Katy Carr, Assistant Provost for Research