The Impact of Project-Based Learning on Students in High School Chemistry in Rural Maine

Brianna DeGone
University of Maine, brianna.degone@maine.edu

Follow this and additional works at: https://digitalcommons.library.umaine.edu/etd

Part of the Chemistry Commons, Curriculum and Instruction Commons, Curriculum and Social Inquiry Commons, Science and Mathematics Education Commons, and the Secondary Education Commons

Recommended Citation
DeGone, Brianna, "The Impact of Project-Based Learning on Students in High School Chemistry in Rural Maine" (2021). Electronic Theses and Dissertations. 3504.
https://digitalcommons.library.umaine.edu/etd/3504

This Open-Access Thesis is brought to you for free and open access by DigitalCommons@UMaine. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of DigitalCommons@UMaine. For more information, please contact um.library.technical.services@maine.edu.
THE IMPACT OF PROJECT-BASED LEARNING ON STUDENTS
IN HIGH SCHOOL CHEMISTRY IN RURAL MAINE

By

Brianna DeGone

B.S. Bioengineering, University of Maine, 2018

A THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science
(in Teaching)

The Graduate School
The University of Maine
December 2021

Advisory Committee:

Susan R. McKay, Professor of Physics, Director of the Maine Center for Research in STEM Education, Advisor.

François G. Amar, Professor of Chemistry and Honors Faculty, Member of Maine Center for Research in STEM Education

Alice E. Bruce, Professor and Chair of the Department of Chemistry
THE IMPACT OF PROJECT-BASED LEARNING ON STUDENTS

IN HIGH SCHOOL CHEMISTRY IN RURAL MAINE

By Brianna DeGone

Thesis Advisor: Dr. Susan R. McKay

An Abstract of the Thesis Presented
in Partial Fulfillment of the Requirements for the
Degree of Master of Science
(in Teaching)
December 2021

Project-based learning (PBL) is an instructional strategy that is promoted throughout education for its use of active learning and ability to connect to real-world applications. Studies have been conducted on PBL ranging from early elementary grades through graduate courses, however little research considers the effectiveness of PBL at the secondary science level. This thesis considers the use of PBL and describes the implementation of a PBL unit in a rural Maine 11th grade chemistry classroom. The thesis aims to better understand the impact PBL has on students’ content learning and additional skills acquired through the PBL learning process. Along with the impact on student growth, this thesis considers the ability to tailor PBL to students with differing levels of achievement and motivation. Over the course of two weeks, a PBL unit around forensics was implemented through a jigsaw classroom technique to 31 honors chemistry students. The unit includes three evidence-collection assignments and the presentation of a final project by each of the groups. Students were required to collect evidence, share
evidence with their synthesis groups and make connections with the evidence collected to create a final project. Along with the PBL unit, students completed a pre- and post-engagement survey regarding the unit and two self-reflections, one for each week of the study. The engagement survey encompasses overall engagement, interest, and challenges posed throughout the unit. The self-reflections have students reflect on their own abilities to participate in the group and how the group dynamic is progressing. Field notes have been collected along with the student responses to gauge student use of collaboration and critical thinking skills while working in their groups. From the data, 26 of the 31 students met or exceeded the standards addressed in the PBL unit and reinforced a strong understanding of the content by making connections from their evidence and applying their findings to the problem outlined in the unit. Students found the PBL unit to be more engaging and interesting, as well as challenging, as compared to the traditional teaching style used prior to this study. An increase in collaborative and critical thinking skills was observed throughout the unit and increased as the study progressed. Along with field observations of these skills, students were also able to identify their own strengths and weaknesses through self-reflections. Students’ metacognition and ownership of their own strengths and weaknesses drew awareness to the collaborative skills they needed to develop. The four case study students ranging in achievement and motivation levels all displayed growth throughout the study. Students of prior high academic achievement found value in having additional group members working toward a common problem while lower achieving students gained confidence and the ability to participate in group discussion. Motivation levels did not impact student engagement throughout the unit as all four of the case study students were actively participating throughout the study. Overall, 88% of students recommended that this PBL be continued for chemistry students in the future.
# TABLE OF CONTENTS

LIST OF TABLES ............................................................................................................. xi

LIST OF FIGURES .......................................................................................................... xii

Chapter

1. INTRODUCTION ......................................................................................................... 1

   Current Teaching Practices ......................................................................................... 1

   Next Generation Science Standards ............................................................................ 2

   General Overview of Project-Based Learning ............................................................... 3

   Importance .................................................................................................................. 4

   Scope of the Research ................................................................................................. 4

   Research Questions ..................................................................................................... 4

   Organization of Thesis ................................................................................................. 5

2. LITERATURE REVIEW ................................................................................................. 6

   Theoretical Framework ............................................................................................... 6

      John Dewey (1867-1949) ....................................................................................... 6

      Jean Piaget (1896-1980) ....................................................................................... 7

      Lev Vygotsky (1896-1934) .................................................................................... 8
Key Aspects and Features .................................................................................................................................................. 9

Seven Essential Project Design Elements ......................................................................................................................... 9

Seven Project Based Teaching Practices .......................................................................................................................... 10

Jigsaw Technique ................................................................................................................................................................. 11

Learning and Skill Development ........................................................................................................................................... 12

Essential Skills for Creative Problem Solving and Innovation ............................................................................................. 13

Higher Order Thinking ............................................................................................................................................................. 13

Metacognition ........................................................................................................................................................................... 15

Motivation .................................................................................................................................................................................. 15

Implementation in Secondary Education ................................................................................................................................ 16

Advantages and Limitations .................................................................................................................................................... 18

Advantages ................................................................................................................................................................................ 18

Limitations ................................................................................................................................................................................ 19

3. STUDY DESIGN & METHODS ............................................................................................................................................ 20

Project-Based Learning Unit Overview ................................................................................................................................. 20

Jigsaw Classroom Design ......................................................................................................................................................... 21

Evidence Collection Packets .................................................................................................................................................... 22
Final Assessment .................................................................27

Classroom Norms ...................................................................29

Engagement Survey ..................................................................30

Student Self-Reflections ..........................................................30

Field Notes ................................................................................31

Motivation & Achievement Student Selection ..........................31

4. DATA COLLECTION & ANALYSIS ....................................33

Data Collection Timeline ..........................................................33

Content Deliverables ...............................................................35

Evidence Collection Assignments ..............................................35

Cooler & Delivery Truck Evidence ............................................36

Crime Scene & Chemical Evidence ..........................................37

Weapon & Blood Stain Evidence ..............................................38

Final Assessments ....................................................................40

Engagement Surveys ...............................................................42

Overall Fun & Engagement Responses .................................43

Interest & Meaningfulness Responses ....................................45
Appendix A: Evidence Collection Assignments

A.1 Cooler & Delivery Truck Evidence Collection Assignment

A.2 Crime Scene & Chemical Evidence Collection Assignment

A.3 Weapon & Blood Stain Evidence Collection Assignment

A.4 Evidence Collection Packet Rubric

Appendix B: Final Assessment

B.1 Final Assessment Rubric

B.2 Student Samples of Final Projects

Appendix C: Classroom Norms

Appendix D: Discussion Starters

Appendix E: Engagement Survey

E.1 Student Engagement Survey

E.2 Student Responses to Post-PBL Engagement Survey Questions

Appendix F: Student Self-Reflections

F.1 Student Self-Reflection Survey
F.2 Student Self-Reflection Responses after Evidence Collection Groups ............126

F.3 Student Self-Reflection Responses after Synthesis Groups ......................129

Appendix G: Field Note Collection Tracking Sheet ........................................132

Appendix H: Habits of Work Rubric ...............................................................133

9. BIOGRAPHY OF THE AUTHOR ..............................................................134
LIST OF TABLES

Table 1. Frequency of Responses for Overall Fun & Engagement..........................44

Table 2. Frequency of Responses for Interest & Meaningfulness ..........................45

Table 3. Frequency of Responses for Difficulty & Frustration ............................47

Table 4. Frequency of Responses for Recommendation.......................................48

Table 5. Observed Student Collaboration & Critical Thinking Skills ......................56
LIST OF FIGURES

Figure 1. Bloom’s Taxonomy Triangle ................................................................. 14
Figure 2. Jigsaw Classroom Design ...................................................................... 22
Figure 3. Student Selection on Achievement and Motivation .............................. 32
Figure 4. Student Scores on Evidence Collection Packets ................................. 40
Figure 5. Student Scores on Final Projects ........................................................... 42
Figure 6. Frequency of Responses for Overall Fun & Engagement ..................... 44
Figure 7. Frequency of Responses for Interest & Meaningfulness ...................... 46
Figure 8. Frequency of Responses for Difficulty & Frustration ............................ 47
Figure 9. Frequency of Responses for Recommendation ...................................... 48
Figure 10. Self-Reflection Question 1 Week 1 Responses .................................... 50
Figure 11. Self-Reflection Question 1 Week 2 Responses .................................... 51
Figure 12. Self-Reflection Question 2 Week 1 Responses .................................... 52
Figure 13. Self-Reflection Question 2 Week 2 Responses .................................... 53
Figure 14. Observed Collaboration & Critical Thinking Elements ....................... 56
INTRODUCTION

With the author of this thesis being both a Master of Science in Teaching candidate and a current secondary science educator, the objective of this study was to better understand the use of active learning specifically in a chemistry classroom in rural Maine. The active learning strategy to be used in the study was project-based learning (PBL), and it was implemented with a jigsaw classroom technique. Often in science classrooms, students are learning science-related content but are lacking the authentic, inquiry-based exploration that science entails. Even though students have opportunities to participate in laboratory practices through chemistry, most are procedural steps that students merely follow to ultimately determine if they performed the exercise correctly. The intention of implementing PBL in this 11th grade, rural chemistry classroom is to provide these students with an opportunity to solve an overarching, chemistry-related problem in their own way while working in a collaborative environment.

Current Teaching Practices

Lecturing has been a leading mode of instruction within education since universities first began in Western Europe almost 900 years ago (Freeman et al., 2014). Along with lecturing, a study conducted by Wiley, W.H. (1918) discusses the methods of teaching chemistry. This study, conducted more than a century ago, outlines which of three teaching methods; the textbook method, the lecture method, and the laboratory method, is best for teaching chemistry (Wiley, 1918). From his study, Wiley concluded that for immediate learning the textbook method was superior while for permanent learning the laboratory method was superior, and lecture-based learning fell inferior to the other two learning methods (Wiley, 1918).
Over the last several decades, educational research has supported the shift from passive, lecture-based learning to active learning. Freeman et al. (2014) found that active learning increases student performance in science, engineering, and mathematics courses. Through this meta-analysis, 225 studies considered examination scores and failure rates comparing students in STEM courses under traditional lecturing versus active learning (Freeman et al., 2014). The findings of this study concluded that examination scores improved and failure rates decreased when STEM students were instructed through active learning strategies. Many active learning teaching strategies are currently implemented in secondary science education.

**Next Generation Science Standards**

Within the last few decades, both at the federal and state level, there has been a push for science education in public schools to involve more hands-on learning methods for students. The book, "A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas" was published in 2012 and outlined the direction science education should go for students within public education (National Research Council (U.S.). Committee on a Conceptual Framework for New K-12 Science Education Standards, n.d.). This framework shaped the current education science standards known as the Next Generation Science Standards (NGSS). The primary goal of this framework is for students to have appreciation for science and to gain sufficient knowledge and professional skills to conduct scientific inquiry by the end of the 12th grade. The framework is also designed for students to be curious and “careful consumers of scientific and technology information related to their everyday lives” (National Research Council (U.S.); Committee on a Conceptual Framework for New K-12 Science Education Standards, n.d.). As of 2019, 20 states had fully adopted the NGSS and another 24 states had adopted standards based on the K12 Framework (NGSS Hub, n.d.). Of the 20 states that have fully
adopted the NGSS, the state of Maine began its implementation of the NGSS in January of 2013. Although almost nine years have passed since the standards were put into effect in Maine, several school districts within the state are still struggling to educate in a way that aligns with the K12 Framework. Many districts may have switched their assessment strategies, but often the day-to-day lesson plans are dated far before the NGSS was established. The NGSS provides targets for students to reach for each grade from K-5, a middle school standard for grades 6-8 and a high school standard for grades 9-12. For each age group, students have targets in disciplinary core ideas, science and engineering practices, and crosscutting concepts. To meet these performance expectations outlined in the K12 Framework, educators must revise not only their assessment process, but their methods of instruction. One teaching style that better supports the “knowledge-in-use” concept described in the framework is PBL.

**General Overview of PBL**

PBL is an instructional approach that allows for students to learn by doing. Through this model, students gain content-related knowledge while trying to solve problems and challenges that they may face in the real-world (Schuetz, 2018). Characteristics of PBL include focusing on a problem and integrating academic content and skills into project development. The lessons are inquiry-based and designed to give students a voice and a choice in their learning. The integration of feedback and revision is designed to generate student ownership of their learning and promote the ability to communicate their findings all while learning the skills to be successful professionals. (*What Is Project-Based Learning?*; *Noodle*, n.d.). PBL is noted for pushing students to go beyond solely memorizing information but to think critically for long-term retention.
Importance

If students are still being instructed in a traditional format, but assessed through the NGSS, then classrooms in Maine have yet to authentically align with the current science standards. The structure of traditional teaching within science education focuses primarily on content-driven results and lacks the foundational innovation skills such as problem solving, collaboration, and communication needed to become a successful professional (Schuetz, 2018). It is critical that students are being prepared to question and contribute to scientific and technological public interests by the end of 12th grade. To do so, the instructional strategies used in education must provoke curiosity and desire to learn. Students not only need the content, but the skills to use the learned knowledge and an interest in lifelong learning. It is important for educators to provide opportunities that allow students to learn through inquiry, collaboration, and problem solving that encourages the learning process both now and in the future.

Scope of this Research

This research considers the implementation of PBL in a secondary chemistry class in a rural public school in the state of Maine. This course is primarily a third-year course for high school students and, prior to taking chemistry, students have completed physical science in their 9th grade year and biology in their 10th grade year. The scope of this research considers the implementation of a PBL unit that draws upon and reinforces introductory chemistry content.

Research Questions

Through the implementation of PBL in a rural high school chemistry classroom, this study aims to answer the following research questions:
1. In what ways is students’ content learning affected by PBL in an 11th grade classroom in rural Maine?

2. What else in the way of knowledge and skills is acquired by the students through PBL in an 11th grade classroom in rural Maine?

3. How does PBL affect learning for the four selected case-study students that were chosen based on their motivation and achievement?
   a. How do these students engage in the PBL activity?
   b. How are knowledge, skills, and motivation affected for these students?

**Organization of Thesis**

This thesis includes a literature review that encompasses the theoretical framework of PBL, the key aspects and features, learning and skill development, implementation in secondary education, and the advantages and limitations of PBL. The literature review is followed by the study design and methodology used to answer the research questions outlined above along with data collection and data analysis. The results and findings from the research are presented and discussed in the next chapter and the thesis ends with conclusions and suggestions for future work. The thesis also includes appendices, a bibliography, and biography of the author.
LITERATURE REVIEW

PBL is defined as “a teaching method in which students learn by actively engaging in real-world and personally meaningful projects” (What Is Project Based Learning? | PBLWorks, n.d.). Many theorists are credited with influencing the development of PBL through their constructivist theories. By using PBL as an instructional method, teachers can deepen student content understanding and related skills, promote metacognition and motivate students to learn. PBL can be implemented at any age across any subject area. This literature review focuses specifically on the implementation of PBL at the secondary education level and addresses advantages and limitations from this method of instruction.

Theoretical Framework

PBL is a method of instruction that is most frequently credited to John Dewey, dating back to the early 1900’s. Dewey’s belief that learning should occur through experience influenced the structure of PBL, while the social component of PBL aligns closer to Piaget’s and Vygotsky’s theories. Together, these three psychologists have all helped shape PBL as a form of educational instruction.

John Dewey (1867-1949)

John Dewey, an American functionalist, believed psychological processes cannot be broken into discrete parts. He argued that sequences were important to view as one because of the influence each stage of cognition has on one another. Dewey supported that these functionalist ideas should be applied to education and how learners learn (Schunk, 1986). In 1933, Dewey developed his primary epistemological thesis that stated: natural things can only be known as serving the cognitive needs raised within problematic experience. He developed a
secondary epistemological thesis that helped explain his first: the process of knowing, taking place through experience, is a transaction between humans and the world in which humans manipulate natural things (John R. Shook, 2000). This concept of problem orientation through experience is an idea that Dewey believed can drive learning activities in education (Helle, n.d.). Along with the use of a problem or question driving knowledge, Dewey believed that for students to be successful they must interact with their environment around them, including social interactions and interactions with the content.

Jean Piaget (1896 – 1980)

Piaget’s theory of cognitive development depends on four factors: biological maturation, experience with the physical environment, experience with the social environment and equilibration. Equilibration is the biological drive to produce an optimal state of equilibrium between cognitive structures and the environment. It is dependent on the first three factors listed in Piaget’s theory, and according to Piaget, is the central and motivating factor for cognitive development to occur (Schunk, 1986). For cognitive structures to develop, a learner must experience disequilibrium or cognitive conflict. This socio-cognitive conflict leads to reflections on thinking and conceptual change (Helle, n.d.).

Although Piaget never directed his theories toward education, constructivists have adapted Piaget’s theory for learning in an educational environment. Although constructivists have altered his theory, it still stands that students form cognitive structures when learning information and adjust their schemas through assimilation and accommodation. These modifications to schemas occur because of experiences students face in their social and physical environments. Piaget’s theory supports that collaborative learning and active learning are
important instructional strategies for cognitive development to occur in learners. PBL as an instructional strategy incorporates learning through experience, both socially and through interactions with the environment.

**Lev Vygotsky (1896 – 1934)**

Like Piaget’s theory, Vygotsky’s sociocultural theory is also considered a theory of constructivism. However, the Vygotskyan view on learning has a greater emphasis on the social environment and how social interactions affect learning (Schunk, 1986). Vygotsky’s theory states that social interactions are critical, and learning takes place collaboratively between two or more people (Helle, n.d.; Schunk, 1986). Vygotsky also introduced the key concept of the Zone of Proximal Development (ZPD). This is defined as “the distance between the learner’s actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (L.S. Vygotsky, 1978). The idea behind the ZPD is that someone who is more skilled at a task or concept, such as a teacher or peer, can help a learner with understanding material that they were incapable of on their own. Through this social interaction, cognitive change can occur in the learner because of the interaction between themselves and the teacher. Vygotsky’s theory emphasizes the value of self-reflection as it allows for students to have a greater awareness of themselves and their understanding. Determining when to be the teacher or the learner will accelerate the learning process and encourage cognitive change (Schunk, 1986). The social environment of PBL instruction allows students to identify their roles and promote cognitive change through ZPD.
Key Aspects and Features

The Buck Institute of Education has done extensive research on PBL, creating curriculum, informational videos, implementation guides, and other resources for educators to use when aiming to use PBL in their classrooms. The vision is to provide access to quality PBL for students, regardless of their location or background, “to deepen their learning and achieve success in college, career, and life” (What Is Project Based Learning? | PBLWorks, n.d.). The Buck Institute of Education provides a research-based model for “Gold Standard PBL”. There are two guides identifying key features: one on the seven essential elements of project design and another on the seven project-based teaching practices.

Seven Essential Project Design Elements

1. **A Challenging Problem or Question** - The project is framed by a meaningful problem to be solved or a question to answer, at the appropriate level of challenge.

2. **Sustained Inquiry** - Students engage in a rigorous, extended process of posing questions, finding resources, and applying information.

3. **Authenticity** - The project involves real-world context, tasks and tools, quality standards, or impact, or the project speaks to personal concerns, interests, and issues in the students’ lives.

4. **Student Voice & Choice** - Students make some decisions about the project, including how they work and what they create, and express their own ideas in their own voice.
5. **Reflection** - Students and teachers reflect on the learning, the effectiveness of their inquiry and project activities, the quality of student work, and obstacles that arise and strategies for overcoming them.

6. **Critique & Revision** - Students give, receive, and apply feedback to improve their process and products.

7. **Public Product** - Students make their project work public by sharing it with and explaining or presenting it to people beyond the classroom.

**Seven Project Based Teaching Practices**

1. **Design & Plan** - Teachers create or adapt a project for their context and students and plan its implementation from launch to culmination while allowing for some degree of student voice and choice.

2. **Align to Standards** - Teachers use standards to plan the project and make sure it addresses key knowledge and understanding from subject areas to be included.

3. **Build the Culture** - Teachers explicitly and implicitly promote student independence and growth, open-ended inquiry, team spirit, and attention to quality.

4. **Manage Activities** - Teachers work with students to organize tasks and schedules, set checkpoints and deadlines, find and use resources, create products and make them public.

5. **Scaffold Student Learning** - Teachers employ a variety of lessons, tools, and instructional strategies to support all students in reaching project goals.
6. **Assess Student Learning** - Teachers use formative and summative assessments of knowledge, understanding, and success skills, and include self and peer assessment of team and individual work.

7. **Engage & Coach** - Teachers engage in learning and creating alongside students, and identify when they need skill-building, redirection, encouragement, and celebration.

**Jigsaw Technique**

The implementation of group projects in the classroom can be a good strategy to promote cooperative experiential learning (Voyles et al., 2015). However, there are some negative perceptions around group projects as some students do not put in their full effort while in a group setting. This act of “social loafing” results in some students doing less while other members of the group end up doing majority of the work. One strategy to combat the act of social loafing in educational settings is the jigsaw technique. The jigsaw classroom is an educational strategy developed by Elliot Aronson in the early 1970s (The Jigsaw Classroom, n.d.). This research-based cooperative learning technique organizes classroom activities in a way that makes students dependent on each other to be successful. Students are broken into groups and assignments are broken into pieces. Each group is given a different piece of the assignment and then students are rearranged into new groups in which students can share their work. This requires students to take all the pieces from their original groups and use them together to complete the puzzle.

The jigsaw technique was used in the Voyles et. al (2015) study to increase accountability and reduce social loafing in student group projects at the collegiate level. Along with the components of the original jigsaw method, oral communication skills, teamwork skills, and critical thinking skills, Voyles et. al added two additional skills including written and oral
communication skills by requiring notetaking and an oral presentation by the students. The
design of this classroom activity encouraged each group member to make contributions and
equalize contributions among members (Voyles et al., 2015). Through this method, educators
can evaluate individual group members’ contributions and hold each student accountable.

A similar study was implemented in a lower secondary school through a chemistry lesson
on atomic structure (Eilks, 2005). In this lesson, students were in two different group settings.
The students began in learning groups of five to six students. From a common topic, each student
in the learning group was assigned a subtopic. Then groups were mixed up and students with the
same subtopic were grouped together. The subtopic groups learned about their specific
assignment and were then returned to their original learning group where each student shared the
information they learned from the subtopic groups. In the Eilks (2005) study, subtopic examples
included Rutherford’s experiment, structure of the atomic nucleus, and structure of the atomic
shell. Students of this study had positive feedback on the jigsaw technique and found they liked
science lessons more through this method. Overall, students began reflecting on their learning
more through this method and became aware of their communication and social skills (Eilks,
2005).

**Learning and Skill Development**

PBL is an instructional method that aims for more learning targets than that of traditional
instruction. Along with strengthening content knowledge, the use of PBL in the classroom
focuses on the development of innovative skills, higher order thinking, metacognition, and
motivation. The structure of PBL promotes learning opportunities that are interdisciplinary and
student-centered (Eli et al., 2018). This method of instruction allows for students to engage with
one another in real-life learning situations giving them the opportunity to work together and construct knowledge on their own. Because of PBL being driven by the student, it impacts students’ overall awareness of their own understanding and may improve their own motivation (Eli et al., 2018).

**Essential Skills for Creative Problem Solving and Innovation**

Learners of today need to be equipped with not only content knowledge, but with the skills that allow them to solve problems in a world that is rapidly evolving from the industrial era to the knowledge and innovation era. This set of skills includes communication and presentation skills, critical thinking, creativity, collaboration, research and technical skills, and time management. Pearlman (2006) concluded that traditional classroom instruction does not align with the skills needed for this level of innovation. In traditional education, students work alone on short, noncomplex assignments that focus on content memorization (Pearlman, 2006). To educate students not only on content, but on the skills needed for success beyond the classroom, PBL is an instructional method that requires them to practice these skills within education. In PBL units, students experience collaboration within a team, critical thinking through challenging problems, written and oral communication, a strong work ethic, and other skills that align with successful individuals in the working world (Pearlman, 2006). Not only does PBL align with the skills required for post-graduation success but it aligns with the national standards for educational content.

**Higher Ordering Thinking**

Bloom’s taxonomy is a model used to classify educational learning objectives into levels of complexity. In 2001, Bloom’s taxonomy was revised as shown in Figure 1. The main revision
from the original Bloom’s taxonomy model is at the higher ordering thinking level. The skill of “evaluation” went from being the highest order of thinking to the second highest. In the revised model, “creating” became the sixth and highest level of understanding (Bloom’s Taxonomy Revised - Higher Order of Thinking, n.d.).

Figure 1: Original Bloom's Taxonomy triangle compared to the revised version in 2001 (Bloom’s Taxonomy Revised - Higher Order of Thinking, n.d.)

To promote higher order thinking in students, education must provide opportunities for students to work through these skills within instructional practices. Higher order thinking is most effectively developed in a PBL setting (Kwietniewski, 2017). Through PBL, as outlined in the Buck Institute of Education “Gold Standard of PBL”, students are challenged with a problem where they must apply several different problem-solving strategies to form a solution. Through their own critique and revision, the students must work together to create a final product and share their findings to the public (What Is Project Based Learning? | PBLWorks, n.d.). The structure of PBL as an instructional method requires students to progress through the hierarchal
steps of Bloom’s taxonomy, beginning with remembering relevant information that they have learned all the way to creating a final product to present.

**Metacognition**

As outlined in Vygotsky’s view on learning, for cognitive change to occur it is important that learners have awareness on their understanding. When students develop higher level thinking skills, they often develop their metacognitive abilities as well. Metacognition, or the ability to think about one’s thought with the aim of improving learning, allows students to identify their strengths and weaknesses in education. Having the ability to self-reflect on what is a challenge allows students to take the steps necessary for cognitive change to occur. With PBL, learning is student-focused and therefore, creates an environment that promotes student reflection throughout the entire learning process. When learning in a lecture-style format, students who are not understanding material, may be aware, but are not in a position that is comfortable for them to advocate for themselves. PBL promotes an environment where metacognitive reflection is encouraged. When working in a group setting, students can identify which problem-solving strategies do and do not work for them. Both teachers and peers can suggest alternative problem solving strategies to struggling students in a collaborative approach. The choice, motivation, and autonomy embedded within PBL allows for students to learn effective tactics for learning that work for them. It is beneficial for student reflection to be a structured part of their PBL experience.

**Motivation**

When students are motivated to learn, the process of learning shifts from being teacher-focused to student-focused. When learning becomes focused on the student, and the educator
takes on a facilitator role, student’s overall engagement in the activity increases. PBL begins with a driving question to motivate learning. By presenting content through a problem or a challenge, students are eager to find a solution. Along with students being driven to solve the problem, presenting their findings is another motivating component for students’ participation in PBL (Darling-Hammond, 2008). Finding the solution to a challenge and then presenting out to an audience makes the students’ education experiences relevant more to real-world applications. When students can acknowledge the direct benefit from learning opportunities, they are more likely to be motivated and engaged in the activity. PBL encourages students to be motivated both intrinsically and extrinsically. When students are interested in the content, such as relevant, real world questions asked through PBL, they will be motivated intrinsically (Kwietniewski, 2017). Extrinsic motivations are reward-driven behavior which is the traditional mode of motivation students receive. With traditional instruction, students are motivated by external rewards such as grades, praise, and the goal of success. However, this type of extrinsic motivation often adds stress and dislike to the learning process. Being motivated from within and from external factors will increase student engagement within education.

**Implementation in Secondary Education**

PBL is an instructional method that has been implemented from early elementary grades all the way through graduate courses. For this literature review, we will focus on the implementation of PBL in secondary education. Although typically considered to be primarily for STEM education, the effectiveness of PBL appears to be effective across all subjects.

Harris et. al (2015) conducted a quasi-experimental study by implementing PBL in an urban, underrepresented school district to 1700 sixth graders. The study focused on the extent in
which PBL could be implemented with fidelity and what impact the implementation had on student learning and other skills during a physical science unit. The teachers in the PBL-implementation group were provided instructional guidance and professional development from administration on the implementation of PBL. This study found the PBL curriculum materials improved student learning as compared to the traditional instruction method. Students at lower achievement levels benefited as much as higher-achieving students during the activity. Educators claimed that the pacing guides and administrative support were useful tools during implementation (Harris et al., 2015).

Hernandez-Ramos and De La Paz (2009) studied PBL in an 8th grade class where students learned to create multimedia mini-documentaries in a 6-week history course (Hernández-Ramos et al., 2009). These students, as compared to those learning from traditional instruction demonstrated positive affective benefits and significant content knowledge as well as critical thinking skills (Hernández-Ramos et al., 2009; Kokotsaki et al., 2016). Another study by Boaler (1998) conducted a PBL environment in a mathematics course for students from ninth grade to eleventh grade. In mathematics, students typically follow rote problem-solving strategies and memorization to answer questions. The creativity and deeper thinking required in the PBL activity allowed students to gain a deeper conceptual understanding than students in traditional math courses (Boaler, 1998).

Holm (2011) performed a meta-analysis on the effectiveness of PBL from prekindergarten to twelfth grade. The studies reviewed were all from the first decade of the 2000s and found that PBL, across all grades and subjects, improved content learning, led to higher levels of engagement, and resulted in more positive perceptions of the subject matter (Holm, 2011). The studies reviewed in the meta-analysis found that PBL resulted in stronger
problem-solving skills among the participants and a greater depth of conceptual knowledge with transferable skills (Holm, 2011; Kokotsaki et al., 2016). Project-based instruction exemplifies a strong benefit for student development, yet the implementation of PBL as an instructional practice poses difficulties for teachers. When teachers are supported in the implementation of PBL, both the teachers and the students benefit.

**Advantages and Limitations**

**Advantages**

As stated above, the implementation of PBL in the classroom has several known advantages. PBL units align with the real-world challenges that students will face after graduation. Not only is it important to educate students with content knowledge but practicing innovative skills will prepare students to handle real-world problems. The ease of scaffolding and differentiating through PBL creates instruction that is student-centered and promotes a better understanding of communication skills, creativity, critical thinking, and time management. The multiple avenues to solve PBL challenges allows for students to reach the higher-level thinking skills outlined in Bloom’s taxonomy through student voice and choice. Research supports that students are more engaged and motivated through PBL instruction and have more opportunities for metacognition and self-reflection. Unlike traditional instruction, PBL incorporates presenting information to others once they have solved their problem. This experience allows students to understand material at a deeper conceptual level rather than through memorization. PBL can be implemented across all subjects and all grade levels which is another advantage to this versatile method of instruction.
Limitations

A main concern around the implementation of PBL is teachers not having enough support in providing PBL lessons to their students (Harris et al., 2015). To implement PBL effectively and with fidelity, teachers need proper guidance, targeted professional learning experiences, and support from their administration. Without these elements, the implementation of PBL may appear too daunting of a task for educators. Standardized testing is a concern with the implementation of PBL as well. Research supports that students learn content knowledge better through project-based instruction as compared to traditional instruction, but this method of learning may make standardized tests challenging for students. For secondary education students, standardized tests such as the SAT, the ACT, or AP exams still have a serious impact on their collegiate opportunities after graduation. It is important that students understand content conceptually, but with the current form of public education, students still must test well to show their content knowledge is strong. The time requirement of PBL is another drawback for teachers (Kwietniewski & Macho, 2017). PBL requires much more time, both in design and implementation than traditional instruction. However, it is important to note that although a PBL unit may take more time than a traditional lesson plan would, more concepts can be embedded into the driving question. One teacher who implemented PBL stated that although she was concerned about timing, it was soon realized that because of the strong student understanding from PBL, she saved time by not having to go back and reteach content (Kwietniewski & Macho, 2017).
STUDY DESIGN & METHODS

The overall design for this study was composed using two main components: deliverables for the students and data collection materials for the author. The student deliverables included a modification of a pre-existing PBL unit that encompasses evidence collection and a final project associated with the overarching challenge of the unit. With the student deliverables, students were tasked with collecting evidence through calculation-based and experiment-based activities. The use of multiple approaches to collecting evidence allowed for the 11th grade chemistry students to apply several different chemistry concepts to the problem addressed in the PBL unit. Their collaborative efforts were observed by the author and an instructional coach within the district. Field notes were collected during the students’ group work along with students being asked to reflect on overall group dynamic and engagement through surveys. The outlined methods used in the study design were created with the intention of aligning with the research questions and meeting the needs of the students involved in the study.

PBL Unit Overview

The curriculum unit used in this study was a modification of “Forensics in Chemistry: The Case of Kristen K”, a PBL unit developed by Sara McCubbins and Angela Codron for the National Science Teaching Association. The original unit was designed for a second-year chemistry course and suggested 25 days to complete ((McCubbins & Codron, 2012). The original unit was adapted for this study to align with first year chemistry content and require less of a time commitment, allowing the unit to be completed in 10 days. After the modifications, the unit was comprised of three evidence collection assignments as shown in Appendix A. Each of the assignments was composed of two parts: one focused on finding evidence through
calculations while the other focused on collecting evidence through a lab activity. The three evidence collection assignments were differentiated to cover content that tailored to lower-achieving students, students at standard level and higher-achieving students. In two different honors chemistry courses students were split into three groups of five or six (n=31), each group focusing on one of the evidence collection assignments. Once the evidence collection groups had completed their tasks, students were rearranged into new groups; five groups of three or four students per class. In the new groups one student from each of the original evidence collection groups was working with a member from the other two evidence collection groups. In these groups, students were to share the information they concluded from the evidence collection assignments and make connections to solve the common problem outlined in the forensic case. The strategy of rearranging students among groups is known as the jigsaw technique and was used as a tool to differentiate instruction cohesively while encouraging collaboration among the students.

**Jigsaw Classroom Design**

The jigsaw technique was used during this study to reduce the time required to complete the activity so it could be more easily implemented in classrooms and to encourage active participation among all students. Through the jigsaw technique, each student contributes a piece and is critical to the completion of the puzzle or in this case, solving the forensics unit. To do so, students were divided into three groups, one for each of the evidence collection assignments. One week was spent collecting evidence within the evidence collection group. During the second week of the study, student groups were rearranged into synthesis groups. The main objective of the synthesis groups was to gather the information from each of the evidence collection groups and work together to make connections to solve the murder outlined in the unit with reasoning.
from all of the evidence collected. The synthesis groups consisted of three students, one from each evidence group. The jigsaw classroom technique was implemented due to the effectiveness it had in the Voyles et al study (2015) on improving student accountability in group projects (Voyles et al., 2015).

Evidence Collection Assignments

The evidence collection assignments were all designed to strengthen student understanding on chemistry content that students had learned prior in the year. The idea behind each of the evidence collection assignments was to allow for a natural differentiation in the classroom. To incorporate differentiation through the jigsaw technique, some evidence collection groups worked on reinforcing content while others learned new content. The first evidence collection packet included concepts that were covered on multiple occasions throughout the students’ high school science courses. By the time of this study, students should be meeting the standards in these content areas including, density, unit conversion, data interpretation, gas laws, and kinetic-molecular theory. Generally, students who were struggling in chemistry were assigned to this group, The Cooler & Delivery Truck Evidence, which was considered the lowest
of the three collection groups. The second collection group, Crime Scene & Chemical Evidence, touched on more challenging, but previously taught content areas, reinforcing their knowledge of empirical formulas, percent composition, stoichiometry, limiting reactants, and percent yield. These ideas were covered previously in the year with students and were new to them at the beginning of this chemistry course. Requiring these students to use concepts that they had only used once and months prior is what made this group designed for students meeting the standards. The third group, Weapon & Blood Stain Evidence, was considered the most challenging of the three groups. Along with reinforcing more challenging content like stoichiometry, students were also introduced to new content they had not yet learned in class including molarity, pH calculations, and acids and bases. This allowed for the higher achieving students to be challenged with learning new content along with solving their portion of the unit. By incorporating this level of differentiation, each student was still contributing to the overall investigation, yet were working at the appropriate level for their skillset.

The first of the three evidence collection units is the Cooler & Delivery Truck Evidence as shown in Appendix A.1. This evidence collection group has two parts: the first part focused on the cooler evidence. In this part, students had to apply their knowledge of density to determine the crime scene location. From the background information provided in the evidence collection packet, students were informed that a local recycling plant had called in to report a suspicious cooler that had been brought into the plant. The cooler had a bullet hole in it and was wrapped in chains. The remains of the blue cooler were then collected as evidence for the case. Students were then given pieces of “recycled plastics” from the plant, all of which had differing densities. Students had to use this sample from the plant to determine the density range of the cooler in which the suspects tried to hide the body. With this information, the group was able to
determine which body of water the police should be looking in and if the suspects were successful in disposing of the body with the cooler. From there, the students had to plan & carry out their own investigation using density as a physical property. The students determined the density range using a variety of liquids with known densities to determine that of the blue cooler pieces in the sample. Once the density range of the cooler was determined from the investigation, students could then make connections between the densities of the liquids to the densities of the lakes in the surrounding area. They then used cause and effect to conclude that the cooler would have only needed a bullet hole and chains if it failed to sink in the first place. With this information, the students searched for a lake with a greater density than the cooler & the crime scene was narrowed down to one lake in the area. The second part for this group regarded how airbags worked and in particular, the airbags in the delivery truck on the scene. Students were informed that there was a delivery truck that was found at the bottom of the lake they had identified and the airbags had not deployed. It was up to the students to determine if the truck could be extracted from the lake without exploding the airbags in order to preserve all possible evidence on board. When providing students with the calculated pressures from the depths of the lake, they determined if the airbag would exceed its volume limit through gas law calculations. Students were then required to relate their findings back to the specific gas law they used, the relationship between pressure and volume, and they were asked how this relates to the kinetic-molecular theory.

The Chemical & Crime Scene Evidence collection assignment was broken down into two parts as well: a calculations-based section regarding unknown substances found in the delivery truck and at the crime scene and an experiment-based section based on crime scene soil samples. In the calculations-based portion, students were given percentages of elements found
from the chemical evidence. They were instructed to help police determine if the chemical analysis matched any of the suspects at the crime scene. To do so, students had to apply their understanding of percent composition and determine each substances’ empirical formulas. With this information, students could begin to identify substances from a list of possible compounds. One of the substances on a suspect was unidentifiable through empirical formula calculations. Students were then given background information that the suspect with this unknown substance on them was at her bakery the day prior. To identify the substances, students have to calculate the limiting reactant within a chemical reaction that is required to make the vanilla flavoring at the bake shop. Through stoichiometry, students identified the unknown substance and how it could be potentially hazardous outside of baking. After identifying all the substances both at the crime scene and on the suspects, the Chemical & Crime Scene Evidence group were given soil samples to conduct their experimental section. Students planned their own investigation with these samples to compare the samples from the suspects to that of the crime scene. Through qualitative observations via microscope, students identified similarities and difference among the samples allowing them to continue building evidence toward the case and which suspects were present at the scene of the murder.

The third evidence collection assignment, which can be found in Appendix A.3, was the Weapon & Blood Stain Evidence assignment. This group was primarily composed of higher-achieving students as new chemistry concepts were introduced in conjunction with some more challenging concepts that were learned earlier in the year. In the first part of this evidence collection, students were able to extract a fingerprint off of a piece of evidence and compare it to the fingerprints of the suspects. Students had not worked with fingerprinting prior to the lesson nor with any samples as delicate as a single fingerprint. These students conducted research on
proper techniques to extract fingerprints, had to gather the best tools to do so, and spent much time practicing before working with the only sample. From there, students had to use qualitative observations to compare the fingerprint from the piece of evidence to the fingerprinting files on each of the suspects. Once the suspects were narrowed down through fingerprinting, the students began their calculations section regarding stains found on the suspects’ clothes. Students were provided [OH] and [H_3O^+] concentrations of each stain but had not worked with pH calculations before. Students had to determine how to calculate pH as a group, if these stains could be considered blood stains, and if not, what the other stains may be depending on the suspect. The students then had to correlate the blood stains to blood types and relate the blood types back to the stains and the victim. Once blood stains were correlated to the blood of suspects, students starting building their case for the investigation. Through this evidence collection group, students determined that there was actually a second victim in the case.

When working through the evidence collection assignment, each group had a packet of background information, prompted questions, and a suspect list that were adapted from the National Science Teaching Association unit. Within these evidence collection packets were two parts for each of the three different groups. Each evidence collection group had a section that was calculations-based which required the students to work with evidence that was provided to determine how the information applied to the forensic case. The second section for each of the groups was experiment-based. Within the experiment section, students in each group were able to work with laboratory equipment, make observations and draw conclusions from the information they collected from the evidence. For the week that students worked in their evidence collection groups, they would retrieve their forensic folder at the beginning of class, work among their group for the forty-minute class period and return the folder to the designated
location when class period ended. This procedure was enforced so no outside work could be
done on the project and all problem solving was to be done collaboratively in their groups. To
assess content understanding, evidence collection packets were submitted to the teacher after the
final assessments were complete for grading based on the evidence collection grading rubric in
Appendix A.4. Students were assessed on their responses to each of the questions along with the
quality of their work. Student understanding was further assessed in how their evidence was
presented in their final project completed by the synthesis groups. If evidence was incomplete or
unclear from any of the evidence collection groups, the student from that section was held
accountable for had not sharing their data in a comprehensible manner.

Final Assessment

After students completed their evidence collection assignments in week one, students
were rearranged into new groups for their synthesis work. The synthesis groups were composed
of one student from each of the three evidence collection groups with the intention of sharing
their findings from week one and bringing that information into their new group to make
connections and ultimately solve the problem outlined in the PBL forensic unit. The final
assignment, as outlined in Appendix B, was for students to form a solution to the forensic case
including murderer(s), motive, and potential timeline of events by supporting it with evidence
collected through the evidence collection groups. Students were then asked to share their
findings and scenarios through a method of their choosing which included but were not limited
to forensic boards, concept maps, PowerPoints, and courtroom skits. To assess if all students
were participating and understanding the evidence collected from their initial groups, students
were unable to present out their own data during the final assessment. This required students to
be clear in sharing out their evidence collections and for the students learning new material to
pose questions often until they understood. The final assessment aimed to focus on students’ communication skills and ability to connect ideas. These skills are displayed through the presentation of their project to the class, along with their ability to communicate and connect ideas through the evidence gathered in the original groups.

Through both portions of the PBL unit, the evidence collection and final assessment, all students had the opportunity to practice several of the disciplinary core ideas, science and engineering practices, and crosscutting concepts outlined in the NGSS. The evidence collection assignments for each of the groups reinforced several disciplinary core ideas from earlier grades along with targets at the high school grade level. Of the disciplinary core ideas, PS1.A Structure and Properties of Matter, PS1.B Chemical Reactions, PS3.B Conservation of Energy and Energy Transfer were all covered within this PBL activity. For science and engineering practices, students develop and use models, plan and carryout investigations, use mathematics and computational thinking, and construct explanations and design solutions as illustrated in each of the evidence collection groups above. There are also connections to the common core state standards in ELA/Literacy and mathematics through this PBL Unit. Of the ELA/Literacy standards, this unit includes RST.9-10.7: Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. (HS-PS1-1) RST.11-12.1: Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS1-3), (HS-PS2-6). Some mathematics standards that were covered include HSN-Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in
graphs and data displays. (HS-PS1-3), (HS-PS1-8), (HS-PS2-6) and HSN-Q.A.2: Define appropriate quantities for the purpose of descriptive modeling. (HS-PS1-8), (HS-PS2-6).

**Classroom Norms**

Before breaking the students into their first groups, the expectations of collaboration were discussed with the class. Prior to this study, students may have a different understanding of collaboration and working in groups. To ensure that all students were aware of the expectations and prepared to practice collaboration effectively during this study, classroom norms and discussion starters were provided to each of the students. Five classroom norms were explained to the students by the teacher and displayed daily throughout the duration of the study. These classroom norms, referred to as the “5Ps” can be found in Appendix C and include: Pausing (“Share the Air”), Paraphrasing, Posing Questions, Putting Ideas on the Table, and Paying Attention to Self & Others. The purpose of having these classroom norms established and easily accessible was for students to reference how they should be behaving within their group throughout the PBL activity to ensure effective communication was occurring. Not only were the norms addressed, but a list of discussion starters was provided to each student on how to practice these norms within conversation. The discussion starter worksheet, as shown in Appendix D, was provided so students had assistance in how to enter conversations and ask questions while practicing the outlined norms. From this list, students had sentence starters for paraphrasing, elaborating and clarifying, synthesizing conversation, supporting ideas with evidence, and building on or challenging group conversation. With effective communication being a new skill for the students in this study, it was important to provide a resource on how to be successful during this activity. All students were required to use phrases from the list at the beginning of the
activity to remove any stigma from students choosing to use the list. Once all students grew more comfortable with the phrases on the worksheet, students did not need to rely as heavily on it.

**Engagement Survey**

Along with understanding the effectiveness of the implementation of a PBL unit in a chemistry course, student engagement and overall enjoyment of the activity were also important data to collect. Students were given a twenty-five-question engagement survey, which can be found in Appendix E, before and after the forensic unit. Before the unit was implemented, students were asked to consider their overall engagement in the course thus far. Prior to the PBL unit, the chemistry courses consisted of a combination of notetaking, activities, lab experiments, worksheets, games, etc. Students assessed their own engagement pre- and post-activity by responding to the survey questions through a linear scale response ranging from strongly agree to strongly disagree.

**Student Self-Reflections**

Students participated in self-reflections once at the end of their first week with their evidence collection groups and once again after the second week with their synthesis groups. With the class period only being forty minutes, the self-reflections were brief with only four questions for them to respond to via Google Forms, as shown in Appendix F. The questions asked the students to identify which collaboration element(s) they felt they were practicing well, which they could work on, and how their group was working together overall. Students were encouraged to provide some positive and negative examples that they had noticed in their group dynamic. The last question on the self-reflection surveys was an opportunity for the students to provide recommendations on the activity or overall flow of the PBL teaching method.
Field Notes

While students were working in their groups, the author collected notes on the observables from the students’ behaviors. Field notes were collected daily, through a tracking sheet that can be found in Appendix G, and focused on two main skillsets: collaboration and critical thinking. For collaboration indicators, the author looked for students practicing the specific skills outlined on the discussion sentence starter handout. These included pausing, paraphrasing, synthesizing and summarizing, using evidence, and building on and challenging ideas. Critical thinking, although an overlap, focused on students sharing ideas, generating questions, evaluating information, making connections, identifying patterns, and applying to solve problems. The author listened for specific quotes that exemplified these skills and noted the frequency of students practicing effective communication strategies five of the days of the study. Along with these skills, students’ abilities to stay on task for the duration of the forty-minute class period were also noted.

Motivation & Achievement Student Selection

Along with collecting observations on student communication and critical thinking abilities within the study, four students were selected for more in-depth consideration based on their motivation and achievement levels. When designing the study, it was important to consider how PBL affects students with differing levels of motivation and achievement. Four students were selected as a case-study within the overarching study to consider the effects that motivation and achievement have on the impact of PBL in an introductory chemistry class. These students were chosen as follows: one with high motivation - high achievement, one with high motivation - low achievement, one with low motivation - low achievement, and one student with low
motivation - high achievement. To select these four students, motivation and achievement had to be assessed. The selection process for motivation considered students’ Habits of Work grades as found in Appendix H. Habits of Work grades are a tool used by the school district to assess students on their responsibility, respect, assignment completion and time management. This tool provides a gauge for students who are motivated to do well in school but may have a lower grade in the class because they struggle with the content. The selection process for student achievement was more straightforward and based on the student’s overall GPA and first attempts on assessments in chemistry. This unit was implemented at the end of May so student achievement was assessed on grades collected in the first nine months of the course.

Figure 3: Student Selection on Achievement and Motivation
DATA COLLECTION & ANALYSIS

The data collection occurred within two advanced chemistry courses in an 11th grade, rural Maine classroom. Between both classes, the sample size was 31 students who were all taking chemistry for the first time. Due to hybrid instruction during the 2020-2021 school year, students were in person four days a week for forty minutes a class period at the time of this study. Data collection included two deliverables related to content. Each student turned in their evidence collection assignments, as shown in Appendix A, from the first week of the unit that was completed with their evidence collection group. After the second week, the synthesis groups presented a final assessment, as shown in Appendix B.2, that proposed a murderer, motive and timeline of the forensic file based on the cumulative evidence collected in week one among the group members. Along with project-based assessments, students completed pre- and post-PBL engagement surveys and weekly self-reflections. Student responses along with the five days of field notes monitoring group communication and critical thinking were analyzed. Additional breakdown was considered for the four students selected based on their motivation and achievement. Below is a calendar to show the data collection and the daily tasks of both the teacher and the student throughout the study.

Data Collection Timeline

<table>
<thead>
<tr>
<th>May 2021</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td>Tuesday</td>
<td>Thursday</td>
<td>Friday</td>
</tr>
</tbody>
</table>

Green Text = Teacher Tasks
Blue Text = Student Tasks
Data Collection Timeline Cont.

<table>
<thead>
<tr>
<th>5/10</th>
<th>5/11</th>
<th>5/13</th>
<th>5/14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Print ten copies of each of the evidence packet assignments. *(Two classes with 15 students per classes. <em>Three different evidence packets, so each evidence collection group has 5 students.)</em></td>
<td>Prepare the materials for each of the evidence collection groups’ lab activities. 1. Density Lab 2. Soil Composition Lab 3. Fingerprint Analysis Lab</td>
<td>Provide students with a better understanding of PBL:  - Explain the forensics case  - Explain their jigsaw groups  - Discuss collaboration expectations &amp; classroom norms</td>
<td>Place students in evidence collection groups. Five students per group: 1. Cooler &amp; Delivery Truck Evidence 2. Crime Scene &amp; Chemical Evidence 3. Weapon &amp; Blood Stain Evidence Collect Field Notes (teacher &amp; instructional coach)</td>
</tr>
<tr>
<td>Return parental consent forms to participate in the study.</td>
<td>Complete Assent Form/Engagement Survey</td>
<td></td>
<td>Get familiar with the forensic case. Read background information &amp; suspect lists that have been provided <em>(different info provided to each group)</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5/17</th>
<th>5/18</th>
<th>5/20</th>
<th>5/21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collect Field Notes (teacher &amp; instructional coach)</td>
<td>Collect Field Notes (teacher &amp; instructional coach)</td>
<td>Collect Field Notes (teacher only)</td>
<td>Wrap up data collection from parts 1 &amp; 2 of their evidence collection group assignments. Make sure each group member has their packets completed and understand the material well to share with their next group.</td>
</tr>
<tr>
<td>Work on Part 1 of their evidence collection group. 1. Background information with density lab activity 2. Determine chemicals at the crime scene through empirical formula and percent composition calculations. 3. Background information with</td>
<td>Complete first self-reflections via Google Forms. Wrap up Part 1 of their evidence collection groups. 1. Dimensional analysis calculations with density activity data. 2. Determine what unknown chemicals are through stoichiometry and percent yield.</td>
<td>General data from self-reflections are shared with the class. Evidence collection groups begin Part 2 in their evidence assignments. 1. Gas law stoichiometry and ideal gas law calculations to determine crime scene location. 2. Analyze composition of the soil at the</td>
<td></td>
</tr>
</tbody>
</table>
### Data Collection Timeline Cont.

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/24</td>
<td>Groups are rearranged into synthesis groups (3 per group). Evidence from each of the evidence collection groups is shared out.</td>
</tr>
<tr>
<td>5/25</td>
<td>Collect Field Notes (teacher only) Students work on solving the forensic unit problem by making connections through evidence. Begin working on final project.</td>
</tr>
<tr>
<td>5/27</td>
<td>Continue work on final projects and plan how they will present them to the class. Complete second self-reflection via Google Forms.</td>
</tr>
<tr>
<td>5/28</td>
<td>Assess final projects and presentation skills via rubric. Synthesis groups present work that include the murderer, motive and timeline backed by evidence. Complete Engagement Survey.</td>
</tr>
</tbody>
</table>

### Content Deliverables

**Evidence Collection Assignments**

Students were broken into groups of five to six students among the three evidence collection groups. The three evidence collection groups varied in difficulty with the Cooler & Delivery Truck Evidence being designed for lower achieving students, Crime Scene & Chemical Evidence group was designed for the average achieving students, and the Weapon & Blood Stain group was designed for the higher achieving students. Tailoring each of the evidence collection assignments to a variety of achievement ranges allowed for a natural differentiation throughout the PBL study.
Cooler & Delivery Truck Evidence

The students working in the Cooler & Delivery Truck Evidence group had the objective of determining the crime scene location and how crime scene evidence could be recovered. To answer the three questions outlined in the purpose as shown in Appendix A.1, students must use content-based knowledge regarding density, data interpretation, dimensional analysis, gas laws, kinetic molecular theory, and surface tension. As outlined in the NGSS, students must be able to meet the disciplinary core ideas related to the content areas above within the public education system. Along with the content, students must show competence in science and engineering practices and crosscutting concepts. The Cooler & Delivery Truck Evidence collection assignment allowed students to plan and carry out their own investigation which included experimental design, data collection, and the refining of their methods if necessary. Students were given fragments of a cooler that was evidence from the investigation and were required to use it to determine the crime scene location. The two groups of students who worked through this assignment used liquids of varying densities to determine the cooler density. Once the range of the cooler density was determined, students evaluated where the crime scene was located based on the densities of surrounding lakes in the area.

Once the crime scene location was determined, students were informed that a delivery truck was in the lake and held critical evidence to the investigation. Students had to perform calculations to determine if the truck could be extracted from the lake without the airbag deploying and destroying evidence. Once evidence collection was complete, students kept their evidence collection packets to use for sharing their information out in their synthesis groups and connecting their findings with the other evidence collected. After the final project presentation from the synthesis groups nine of the ten students from the Cooler & Delivery Evidence group
submitted their packets. Of these nine students, eight of the students in this group met the standards for both the calculations and experimental sections as shown in Figure 4. Six students exceeded the standards, two scoring a 3.5 and four students scoring a perfect 4 per the requirements on the grading rubric as shown in Appendix A.4. For the one student who did not meet the standard, several of the packet was incomplete, but showed understanding on the completed sections. Further assessment of students’ content understanding was determined through their ability to share their findings with their synthesis groups in a way in which their other group members could present this data in the final presentation.

*Crime Scene & Chemical Evidence*

The students working in the Crime Scene & Chemical Evidence group had the objective of identifying crime scene evidence and determining any potential matches between the evidence and suspects of the case. To answer the questions outlined in the purpose in Appendix A.2 students must use content-based knowledge regarding empirical formula, percent composition, stoichiometry, limiting reactants, percent yield, and making qualitative observations of physical properties. The eleven students who were assigned this evidence collection assignment were provided with percentages of each element found in unknown substances from the crime scene. Students had to recall how to calculate empirical formulas to determine possible compounds that these substances could be. One of the two groups recalled the empirical formula equation and quickly identified each of the substances. The other group initially worked backwards and converted the possible compounds list to percent compositions. Although the process was significantly longer, both groups were able to utilize their computational thinking capabilities to identify the unknown substances and solve the overarching problem. Students were then provided percentages of elements found on each suspect. Through more data analysis, both
groups were able to connect compounds to the suspects and the crime scene. This information allowed students to make connections to why each of the compounds were found on certain suspects and if they were present at the crime scene location. One of the chemical compounds was not provided as a possible compound match so each student performed stoichiometry and found that an excess reactant to a chemical reaction was what was found on a suspect. This related the unknown chemical to a component used in making vanilla flavoring and one of the suspects was a baker.

Along with calculations, the Crime Scene & Chemical Evidence groups were provided with soil samples collected from the soles of each suspects’ shoes. The groups had to create their own slides and look at the samples under a microscope to observe similarities and differences between the suspects shoes and the crime scene soil. At the end of the evidence collection group, all nine students who turned in their evidence collection packets met the standards as shown in Figure 4. Seven of the nine students supported a strong understanding in the disciplinary core ideas by exceeding the standards and making connections to which of the suspects had been present at the crime scene based on the chemical evidence and soil samples provided.

Weapon & Blood Stain Evidence

The students working in the Weapon & Blood Stain Evidence group had the objective of matching fingerprints of the suspects to prints retrieved from a weapon at the crime scene and matching blood types to stains found on suspects’ clothing. To answer the questions outlined in the purpose as shown in Appendix A.3, students had to use content-based knowledge regarding molarity, pH, stoichiometry, acids and bases, and making qualitative observations of physical properties. The first part of this evidence collection packet was to collect fingerprints from an
aluminum sample wrapped around a weapon at the crime scene. The ten students in this group had to learn best practices in fingerprint collection and develop a plan on how to do so. Both groups of students understood the importance of not destroying the evidence from the crime scene so they created their own samples to practice collecting fingerprints. One student went to get paintbrushes from the art teacher to spread the fingerprinting dust evenly, another asked for scotch tape to use, and after careful execution, both groups were able to get a clear fingerprint from the evidence. Once the print was collected, students collected qualitative data regarding the patterns in the print. Students classified the print collected and compared it to the prints of each suspect provided to them. Both groups classified each of the suspects’ prints as either arch, tentarch, loop, double loop, pocked loop, whorl or mixed. After the prints were classified, students in this group also analyzed stains found on the suspects’ clothes. The students used pH calculations, a content area that had not yet been covered, to determine if the stains could be blood stains or not. To understand pH calculations, both groups dove into textbooks to better understand acids and bases. After the pH of each stain was calculated, all ten students determined if it was a blood stain or not and if so, determined the blood type. Blood types of each suspect and victim were used to make connections to the stains and who’s blood it could be. From their data collection, all nine students who turned in their evidence collection packet met the standards for this evidence section as shown in Figure 4. The group of students were able to successfully form a strong connection between their findings and a possible scenario to link the murderer to the murder. Six of the nine students exceeded the standards by providing more connections to the data than required.

Overall, each of the students’ participated in the evidence collection groups and all but one student had packets that were fully completed after their evidence collection group finished
in the first week of the study. Of the twenty-seven students who submitted their packets after the final presentation, twenty-six of them met the standards with twenty of those students exceeding the standards. Of the twenty-six who met the standards, they submitted work that exemplified a strong understanding of the content both in the calculation and experimental section of the assignment. The students continued to support their understanding through the synthesis groups when they were responsible for sharing this information to others who were not familiar with their specific findings during the second week of the study.

Final Assessments

The week-two synthesis groups were expected to create a final project to present to the class that solved the forensics case based on the evidence collected in the first week of the activity from all three of the evidence collection groups. Students were provided the final assessment rubric, as shown in Appendix B, that outlined expectations and described the student
choice on how they would present their findings. Of the ten synthesis groups within this study, final assessments were submitted in a variety of displays. These projects included PowerPoint presentations, timelines, forensic boards, courtroom skits, and concept maps. Through each of these synthesis projects, students were graded on their project, presentation to the teacher and class, originality, and accuracy. The project had to follow a typical forensics case format and be verbally explained to an audience. The project had to show creativity as students were required to form a narrative by connecting the evidence together rather than solely presenting the evidence independently of one another. The information presented by the students also had to be correct through their use of applying their findings to the problem outlined in the assignment and making connections between the pieces of evidence to the case. To ensure students shared their information from the evidence collection groups successfully, students had to present on evidence that they had not collected in the first groups. This exemplified that students not only were about to perform the calculations and experiments for their own evidence collection groups, but could explain their data and scientific methods in a manner that was understood by their peers. This required students to explain their data, evaluate new information and connect the findings together to solve the overarching problem of this PBL unit. The design of the final assessment promoted higher ordering thinking for both the student presenting and the students learning about the new evidence. Although groups presented together, students were individually graded both on their involvement in the group and their effectiveness at presenting the findings. Individual student grades can be seen in Figure 5. All ten of the synthesis groups met the expectations within their presentation but three of the 31 students did not individually. With a 2.6 being a failing score, three students received a 2.5. The primary reason for not meeting the standard was failure to participate in the presentation. One student had not grasped the evidence
presented by their peers and struggled to make the connections in their portion of the presentation. However, the other two were fairly shy and chose to not to speak much while the remainder of the group presented. The majority of the students met or exceeded the standards in the final assessment. Of the twenty-eight who met the standards, twenty-two exceeded the standards with fifteen of those students receiving a 4 for their final grade. These students exemplified a strong understanding of all the evidence collected among the three groups and supported their narrative through several sources of logic and reasoning. Examples of final assessments can be found in Appendix B.2.

![Student Scores on Final Project](image)

*Figure 5: Individual Student Scores on Final Projects Presented in the Synthesis Groups (n=31)*

**Engagement Surveys**

Students were asked to complete a twenty-five-question survey before beginning the PBL forensics unit and again after the activity was completed. The twenty-five survey questions were written in the form of “I” statements and grouped into three main categories: overall fun and
engagement of the unit (10 questions), meaningfulness and interest in the unit (6 questions), and frustration and difficulty of the unit (8 questions). One question that did not fit in any of these three categories was if students would recommend this activity to friends and family. When students completed the engagement survey before the activity, they were instructed to answer the questions in relation to the general format of the class over the course of the year thus far. For this chemistry classroom, the general class structure includes a variety of taking notes as the teacher presented slideshows, working through laboratory experiments with a partner, completing practicing problems, playing review games, etc. Of the 31 students in the class, 28 students completed the pre-engagement survey. The post-engagement survey was to be answered regarding the PBL unit that the students had just completed. Students spent two and a half weeks working through this forensic activity and 25 of the 31 students completed the survey. The post-engagement survey was completed by students on the last day of school. To allow for comparison between the pre- and post-engagement survey data, the frequency of students’ responses was converted to percentages for analysis.

**Overall Fun & Engagement Responses**

The ten questions in the engagement survey that were focused on fun and engagement were questions #1-#10 as shown in Appendix E. The responses to these questions trended on a typical bell curve format for both the pre- and post-PBL engagement survey. In both surveys, the most frequent response was neutral in which students neither agreed nor disagreed with the questions. 37.45% of students selected neutral in the pre-PBL engagement survey and 32.00% in the post-PBL engagement survey. A higher percentage of students selected ‘strongly agree’ or ‘agree’ when considering the fun and engagement of the forensic unit as compared to the regular format of the chemistry classroom. The selection of ‘strongly agree’ increased 79% from the pre-
PBL engagement survey to the post-PBL engagement survey. Students’ responses for ‘agree’ also increased 12% from pre-PBL to post-PBL engagement survey. There was a slight increase of 21% of students who disagreed with the activity being fun and engaging, going from 18.73% of students selecting ‘disagree’ to 23.60%. The most significant change from the pre-PBL to the post-PBL engagement survey was a 180% decrease in students choosing ‘strongly disagree’. Only 6.40% of students selected this response for the PBL activity.

Table 1: Frequency of Responses for Overall Fun & Engagement
(Pre-PBL Unit n=28, Post-PBL Unit n=25).

<table>
<thead>
<tr>
<th>Responses</th>
<th>Pre-PBL Frequency</th>
<th>Post-PBL Frequency</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Agree</td>
<td>2.39%</td>
<td>11.20%</td>
<td>79%</td>
</tr>
<tr>
<td>Agree</td>
<td>23.51%</td>
<td>26.80%</td>
<td>12%</td>
</tr>
<tr>
<td>Neutral</td>
<td>37.45%</td>
<td>32.00%</td>
<td>-17%</td>
</tr>
<tr>
<td>Disagree</td>
<td>18.73%</td>
<td>23.60%</td>
<td>21%</td>
</tr>
<tr>
<td>Strongly Disagree</td>
<td>17.93%</td>
<td>6.40%</td>
<td>-180%</td>
</tr>
</tbody>
</table>

Figure 6: Frequency of Responses for Overall Fun & Engagement (Pre-PBL Unit n=28, Post-PBL Unit n=25).
Interest & Meaningfulness Responses

The questions in the engagement survey that were categorized as interesting and meaningful were questions #11–#15 and #17 as seen in Appendix E. From the pre-PBL to the post-PBL engagement survey responses, 31% more students responded with ‘strongly agree’ that the PBL unit was both interesting and meaningful. Although the responses for ‘strongly agree’ increased, there was an 18% decrease in post-PBL ‘agree’ responses as compared to students’ pre-PBL responses. The greatest change was the decrease in students selecting ‘strongly disagree’ when considering that the activity is interesting and meaningful. When comparing the frequency before the PBL unit to after, there was a decrease of 881%. Students were far less apt to strongly disagree when considering the PBL forensic unit as opposed to the regular format of learning chemistry content.

Table 2: Frequency of Responses for Interest & Meaningfulness

(Pre-PBL Unit n=28, Post-PBL Unit n=25).

<table>
<thead>
<tr>
<th>Responses</th>
<th>Pre-PBL Frequency</th>
<th>Post-PBL Frequency</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Agree</td>
<td>10.18%</td>
<td>14.77%</td>
<td>31%</td>
</tr>
<tr>
<td>Agree</td>
<td>32.34%</td>
<td>27.52%</td>
<td>-18%</td>
</tr>
<tr>
<td>Neutral</td>
<td>31.74%</td>
<td>35.57%</td>
<td>11%</td>
</tr>
<tr>
<td>Disagree</td>
<td>12.57%</td>
<td>20.81%</td>
<td>40%</td>
</tr>
<tr>
<td>Strongly Disagree</td>
<td>13.17%</td>
<td>1.34%</td>
<td>-881%</td>
</tr>
</tbody>
</table>
Difficulty & Frustration Responses

The engagement survey questions that revolved around the activity being difficult or frustrating for the students were questions #16 and #19-#25. The “I” statements outlined in these questions addressed students’ confusion, annoyance, and discouragement from the activity. There was a 79% decrease in students responding with ‘strongly agree’ meaning less students felt the PBL activity was difficult and frustrating as compared to their normal way of learning chemistry. There was a slight increase of 4% for students agreeing with the statements on difficulty and a 21% increase for students being neutral. Both responses of ‘disagree’ and ‘strongly disagree’ decreased but only at a percentage of 6% and 8%, respectively.

Figure 7: Frequency of Responses for Interest & Meaningfulness (Pre-PBL Unit n=28, Post-PBL Unit n=25).
Table 3: Frequency of Responses for Difficulty & Frustration

(Pre-PBL Unit n=28, Post-PBL Unit n=25).

<table>
<thead>
<tr>
<th>Responses</th>
<th>Pre-PBL Frequency</th>
<th>Post-PBL Frequency</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Agree</td>
<td>7.18%</td>
<td>4.00%</td>
<td>-79%</td>
</tr>
<tr>
<td>Agree</td>
<td>15.38%</td>
<td>16.00%</td>
<td>4%</td>
</tr>
<tr>
<td>Neutral</td>
<td>22.05%</td>
<td>28.00%</td>
<td>21%</td>
</tr>
<tr>
<td>Disagree</td>
<td>35.38%</td>
<td>33.50%</td>
<td>-6%</td>
</tr>
<tr>
<td>Strongly Disagree</td>
<td>20.00%</td>
<td>18.50%</td>
<td>-8%</td>
</tr>
</tbody>
</table>

Figure 8: Frequency of Responses for Difficulty & Frustration (Pre-PBL Unit n=28, Post-PBL Unit n=25).

Recommendations Responses

In the engagement survey, question #18 asked if students would recommend this science activity to friends and family. Responses for ‘strongly agree’ and ‘agree’ both decreased while ‘neutral’ and ‘disagree’ responses increased. The largest percent change was student responses for ‘strongly disagree’ decreasing from 18.52% to 4.00%. Although the recommendation responses do not support the implementation of the PBL activity, the post-PBL engagement
survey included an additional open response question that asked, “Do you think students in the
grade below you should do this activity in chemistry class next year?” When students were asked
to recommend this activity to future students rather than family and friends, 22 students of the 25
responses said yes, students next year should also do this activity.

Table 4: Frequency of Responses for Recommendation (Post-PBL Unit n=25).

<table>
<thead>
<tr>
<th>Responses</th>
<th>Pre-PBL Frequency</th>
<th>Post-PBL Frequency</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Agree</td>
<td>11.11%</td>
<td>4.00%</td>
<td>-178%</td>
</tr>
<tr>
<td>Agree</td>
<td>29.63%</td>
<td>24.00%</td>
<td>-23%</td>
</tr>
<tr>
<td>Neutral</td>
<td>29.63%</td>
<td>40.00%</td>
<td>26%</td>
</tr>
<tr>
<td>Disagree</td>
<td>11.11%</td>
<td>28.00%</td>
<td>60%</td>
</tr>
<tr>
<td>Strongly Disagree</td>
<td>18.52%</td>
<td>4.00%</td>
<td>-363%</td>
</tr>
</tbody>
</table>

"I would recommend this science activity to my friends and family."

Figure 9: Frequency of Responses for Recommendation (Pre-PBL Unit n=28, Post-PBL Unit n=25).
Student Self-Reflections

Students completed two self-reflections during this study. The first was completed on May 18th, 2021 after students had been introduced to PBL and worked with their evidence collection groups for four days. The second self-reflection was completed on May 27th, 2021 after students had spent three days working with their synthesis group. Twenty-six students submitted the first self-reflection and 30 submitted the week two self-reflection. There were thirty-one students in total between the two classes participating in the study.

Question 1 - From the list of classroom norms, what do you think you are practicing well? Why?

When students were asked what they felt they were practicing well after their evidence collection group, 13/26 students felt that they were paying attention to self and others well. This response was followed by 11/26 students believing they were effectively putting their ideas on the table. In the evidence collection group, students were revisiting former content ideas and working in a larger group then they were used to (groups consisted of 5-6 students). Paying attention to how they were feeling, their group dynamic and the involvement of others within the group is a positive response for the evidence collection group. When asked to explain why they felt they were practicing these skills well, one student stated that they were strong in paying attention to self and others because “I believe I do a good job monitoring myself and helping others be a part of the conversation”. Another student who was proud of their ability to pose questions stated that they were “not afraid to speak up when struggling to understand something or need someone to go slower through the packet”. Several students suggested they were performing more that one of the classroom norms well.
After students were rearranged into their synthesis groups, the responses to question one on the self-reflection shifted to 20/30 students stating they were putting ideas on the table and 11/30 students posing questions. In the synthesis groups, students were sharing their findings from week one that their other group members were not yet familiar with. One student felt “proficient at putting ideas forward and incorporating people’s ideas into [their] timeline” while another student mentioned how “everyone was contributing evenly to the discussion”. Having each student put ideas on the table while others pose questions is the main objective of the week two synthesis groups. In both self-reflections, every student was able to identify at least one, if not multiple skills they felt they were practicing well through the activity.
Question 2 - Which of the norms should you work on more? Why?

When students were asked what they could improve on, paraphrasing was the highest element after both self-reflections, 10/26 and 11/30 students, respectively. Paraphrasing is a skill that students are not as familiar with and do not practice often. After the first self-reflection, one student stated that paraphrasing is difficult “because sometimes the topic uses big words we all don’t understand”. When the content is challenging, it may be difficult for students to summarize what their peers are saying. Following paraphrasing on the week one self-reflections were pausing and putting ideas on the table, both with 5/26 student responses. A student who needed to work on pausing said they “sometimes over share and need to work on slowing down and letting others speak and ask questions” while another student stated that they needed to work on putting ideas on the table because sometimes they hope others will answer before they do so they do not have to be wrong. Students’ responses to question two were heavily driven by their confidence levels both with the material and with their peers. For some students, talking to a
group came easier and they identified the need to work on slowing down while other students were less willing to share were aware in the need to put their own ideas on the table. Seeing students reflect on their need for more practice with these skills not only makes them aware of what they are doing well but what they need to work on. In total, between the two self-reflections, students identified a collective 90 norms they were doing well with and 50 norms that needed improvement.

Figure 12: Self-Reflection Question 2 Week 1 Responses (n=26)
Question 3 - How is your group working together overall? What are some positives and negatives that you have noticed?

Of the students who completed the self-reflection during the first week, 15 of 26 students only described a positive experience regarding their group dynamic. Of these students, one stated, “we are working good together, and we are all very comfortable with each other as a group”. Another student felt that “we work well together. Even though we may have differences once in a while on how we would like to go about solving problems.” Not only were students addressing their ability to work through the material, but one even stated that, “our group is good at functioning effectively, and we have a good time as well”. It seemed that all the negatives addressed by students in their responses revolved around “the group seems very split”. One student said, “sometimes people skip ahead, and some people don’t really like to be included”. Another student mentioned group members “going on their own and not explaining their methods.”
For the second self-reflection, 19 of 30 students only provided positive feedback about their group dynamic. The synthesis group was composed of only three students while the evidence collection group included five students per group and several students stated that the smaller group size worked better. Comparing the evidence collection group from week one to the synthesis group one student said it was going “really good. Communication is better, and we are all participating”. Another student outlined that the group work was going “good. We all have a sort of different thought process which can be both good and bad”. In this self-reflection, working well together and contributing equally was a repetitive response. It appears that more students were on task and involved during the synthesis group portion of the activity. As for negative observations, one response mentioned that students are still preferring to work alone and not include their group members. Another mentioned that “not everyone cares about the project, so it sometimes makes me nervous”. Students also mentioned that their groups were “a bit talkative” and “not always on topic”.

**Question 4 - Do you have any recommendations for me?**

As part of the PBL activity, the author felt it was important for students to have voice and choice along with the ability to provide feedback to me regarding the unit. After the first week, only four students provided feedback and several others stated that “forensics is fun” and “my group is working pretty well”. Of the four who submitted recommendations after the first week, one student suggested smaller groups. The synthesis groups were already designed to be groups of three and allowed the students to practice working in larger groups of five and smaller groups of three. One student suggested “focus on collaboration throughout the year so that people get more used to it” and another felt a bit rushed at some points in the activity. Prior to the self-reflections, an instructional coach was assisting in field note collections. However, one student
stated that “having a teacher hover over us and watch makes me very anxious and feel like I can’t be myself in this setting.” After this self-reflection, the field notes were only continued by the author, so the students felt more comfortable.

In the second self-reflection only three students provided recommendations while a few others stated they enjoyed working in groups of three rather than groups of five. Two students recommended giving the option to choose groups while another student suggested going “back into our original groups and discuss what we've discussed in our small groups.” These suggestions by the students will be considered when altering the unit for students in future years.

**Field Notes & Observables**

Field notes were collected for five days of the study. Three of these days included two field note collectors, the author and the instructional coach in the district. The last two collection days only included the author’s observations and were doubled in quantity to account for the differential in data. The field notes consisted of looking for students practicing collaboration and critical thinking techniques via note tracker shown in Appendix G. The first four collection dates, 5/14, 5/17, 5/18, and 5/20 were all days in which students were working in their evidence collection groups of five to six students. Collecting observations between the six evidence collection groups was easier for the observers as compared to ten synthesis groups which accounts for the decrease in collection on 5/25. Prior to the study, the collaboration elements to look for by the observers were narrowed down to pause, paraphrase, elaborate/clarify, synthesize/summarize, use evidence, and build on/challenge. After discussion between the observers, the identification of student’s pausing was ultimately unclear and removed from the element list. The critical thinking techniques to look for included share ideas, generate questions,
evaluate information/arguments, reason, make connections, identify patterns, and apply to solve problems. For each day of field notes, critical thinking techniques were much more frequent than collaboration techniques. Of the critical thinking skills, sharing ideas and generating questions were the most frequently observed skills. For collaborative elements, elaborate/clarify and synthesize/summarize were the most frequently observed among the students.

Table 5: Observed Student Collaboration & Critical Thinking Skills During PBL Unit (n=31)

<table>
<thead>
<tr>
<th>Collection Date</th>
<th>Collaboration</th>
<th>Critical Thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/14</td>
<td>22</td>
<td>52</td>
</tr>
<tr>
<td>5/17</td>
<td>41</td>
<td>60</td>
</tr>
<tr>
<td>5/18</td>
<td>17</td>
<td>64</td>
</tr>
<tr>
<td>5/20</td>
<td>64</td>
<td>90</td>
</tr>
<tr>
<td>5/25</td>
<td>10</td>
<td>46</td>
</tr>
</tbody>
</table>

Figure 14: Observed Student Collaboration & Critical Thinking Skills During PBL Unit (n=31)
Motivation & Achievement Student Analysis

To better understand the effect of PBL on students of differing motivation and achievement, data from the four, selected case study students was extracted from the group data for further analysis. Within this case study, student quotes from field notes, self-reflections and content deliverables are considered.

Student 1 (High Motivation – High Achievement)

On the first day of the study, Student 1 approached the teacher and said, “I’d rather do this by myself”. This student had no interest in a group project and was disappointed with the requirement to practice collaboration. On Monday, 5/17, Student 1 was quoted as saying to their evidence collection group, “I’m overwhelmed. Let’s take a pause and regroup. We’re all at different points.” This observation from the field notes aligns directly with the student’s self-reflection responses. The following day, this student noted that they were pausing and paying attention to others well. When asked why they felt they were practicing these classroom norms well, the student said, “I think I am doing them well because I am checking on my classmates to make sure everyone is on the same page of understanding.” Another quote from 5/17 from this student showed them delegating the work between group members. They said, “I’m doing this one. Let’s share out afterward.” At the beginning of the PBL forensics unit, there were several avenues to explore and information to absorb. Student 1 trusted their peers through delegation and thought regrouping was a useful strategy. In the first self-reflection, this student identified a weakness of needing to work on posing questions because “I should ask how people got that answer/mindset.” With Student 1 being a highly motivated and high achieving student independently, they may struggle to pose questions as they prefer working independently.
Identifying the need to work on this collaboration element shows an understanding of what they need to work on. Also in the self-reflection, students were asked how the overall group dynamic was going and what are some positive or negatives they have noticed. Student 1 stated, “I’ve noticed it’s easier to have more minds sometimes.” This response is a radical shift in mindset from the initial quote on the first day of the study. In the second week self-reflection, Student 1 felt that they were posing questions well “because we are asking questions” and that the student needed to work on “paying attention to self and others because sometimes people cut off other’s ideas”. Between the two self-reflections, the strengths and weaknesses for this student were reversed. The change in responses is most likely influenced by the jigsaw technique and how the group work shifts from working toward a common problem to sharing out ideas and making connections. On the last day of field notes, student 1 was overheard saying, “Look, I’m doing science and I’m good at it!” The student was much more confident by the end of the activity and proud of their understanding. For deliverables, Student 1 met all the disciplinary core ideas in her evidence collection assignment. This student and their synthesis group exceeded the standards for the final assessment both in the overall project and the presentation to the audience.

**Student 2 (High Motivation – Low Achievement)**

Student 2 was noted as quiet on the first day of working within the evidence collection group and worked primarily with one other group member rather than collaborating with the whole group of five students. On 5/18, Student 2 spoke up and was heard saying, “I feel like we should talk about where we’re at.” This student was aware that the evidence collection group had split into two groups and they were trying to unite the group back to one. In the first self-reflection when asked about the overall group dynamic, this student responded with, “I feel like we are not working all that well together. The group seems very split. Half of the group is
working alone and the other half is attempting to collaborate. When questions are asked, they are often ignored. Half of the group seems very focused on finishing the task rather than understanding and working together and understanding what needs to be understood. It’s frustrating when some people are trying to understand and others are shutting them out. It’s hard to understand and keep up when everyone is at a different place and no collaboration from one half is happening.” This student’s awareness of their group dynamic and struggle to get the rest of the group on task was why we decided to anonymously share the data from the first self-reflection in hopes to unite the group. Of the ten groups in this study, this group had the hardest time to work together as a whole. However, regardless of the overall dynamic, Student 2 worked hard to keep sharing ideas and asking questions to create a collaborative environment. The student mentioned, “I feel like we need to know the density” when the group was struggling to develop an experiment to solve the problem they were given. This student also aimed to realign the group by asking everyone what question they were all working on at the moment. Student 2 felt they were listening well and paying attention to others but having a harder time putting ideas on the table. In the second self-reflection, after the groups had been rearranged per the jigsaw technique, Student 2 felt they were doing well at paying attention to others and putting ideas on the table, but pausing was a weakness of theirs. Over the course of the study, this student became more confident in discussing technical content and critical thinking strategies with peers. Student 2 felt their synthesis group was “working pretty well together” as they were “respectful of each other’s ideas”. Student 2’s evidence collection packet was thoroughly filled out and easy to follow making it easy for this student to share information with the synthesis group during the second half of the study. This student spoke confidently when presenting their findings and
explaining how their portion of evidence was collected. Student 2 met the standards in both the DCIs and the science and engineering practices outlined in the study.

**Student 3 (Low Motivation – Low Achievement)**

Student 3 is a student who is regularly challenged by chemistry content and has little interest in learning the material. On the first day in the evidence collection group, Student 3 came up with the idea to use molar mass to begin solving their chemical evidence problem, and the group showed their excitement and shared that with Student 3. This student also did well throughout the study paying attention to themselves and others, frequently posing questions to pause or rephrase information that was being shared. Student 3 was heard interjecting and asking, “can you go a little slower so I can figure it out?” and “I am so confused, can you wait.” Although at times, Student 3 was moderately stressed and confused, this student continued to add ideas to group discussions about identifying unknown substances. When working through the calculations, student 3 stated, “now we have to balance what’s left” to help their group continue progressing through the data analysis. In the first self-reflection, this student felt they were doing well at posing questions and needed to work on putting ideas on the table. When considering their group dynamic, Student 3 responded with, “there are some people who are really smart and just cruise through while others are struggling to actually understand what's even happening.” As the unit progressed, Student 3 became more comfortable with the expectations and was observed making connections between calculation answers and the evidence along with providing explanation to another group member who was confused. Student 3 shifted their strength in the second self-reflection to contributing ideas and listening with needing to work on pausing. When the groups changed from five students to three, Student 3 felt that “[they] all work really well together. There’s less people so I think it’s a lot less clutter.”
Student 4 (Low Motivation – High Achievement)

The fourth student within this case study is a student who performs well, but has little motivation or interest in the curriculum. Throughout this forensic unit, Student 4 felt that they were, “paying attention to self and others because I believe that I do a good job monitoring myself and helping others be a part of the conversation.” Through observations, these skills outlined by the student were supported with them continuously asking questions, and checking in with their group members. To ensure all were on track and working together, student 4 would ask the group, “which graph are we working on now?” and would challenge group member’s ideas in a collaborative, supportive way. In the self-reflection this student identified putting ideas on the table as something they needed to work on. This student said that “because sometimes I hope others will answer before me so I don't have to be wrong.” With this being the first collaborative activity really implemented in the class, Student 4 appeared hesitant to be incorrect in front of their peers. Overall, their group dynamic was considered “pretty good” by the student as work was getting done. However, one of the students within this evidence group struggled more than any of the other students in the class to stay on task. Student 4 tried on multiple occasions to incorporate this student into discussion and improve their engagement. In the second self-reflection, Student 4 felt like their strength had shifted to, putting ideas on the table because everyone is participating very well.” This student also felt that in their synthesis group, they could work on posing questions as the group wasn’t asking a lot of questions, but rather making more theories around the case. The group dynamic for Student 4 also improved and was considered “really good. Communication is better and we are all participating.”
RESULTS & FINDINGS

All thirty-one students were able to participate in the jigsaw classroom design for this PBL forensic unit. In their first week, students were able to practice collaboration and critical thinking techniques within their evidence collection groups. Throughout the three different evidence collection assignments, students used their knowledge of density, gas laws, stoichiometry, dimensional analysis, pH and additional science and engineering practices to collect the evidence required to create a possible scenario to the case. The evidence collection packets collected from the first week supported that twenty-six of the twenty-seven students met or exceeded the standards supporting a clear understanding of their specific disciplinary core ideas. In the smaller synthesis groups, students made connections and applied their evidence to the overarching problem outlined through the assignment. Each group developed final presentations that demonstrated strong critical thinking and presentation skills. Each of the ten synthesis groups presented projects that were accurate, unique, and well-constructed with twenty-eight of the thirty-one students meeting or exceeding the standards.

The engagement survey focused on three different subject areas: fun & engagement, interesting & meaningfulness, and difficulty & frustration. When comparing students’ pre- and post-engagement survey responses, student responses showed that they felt the forensic unit was more fun & engaging along with interesting & meaningful. More students selected strongly agreed & less students strongly disagreed with the “I” statements associated with these types of survey questions. Fewer students felt that the forensic unit was difficult and frustrating as compared to the content prior with an increase on neutral responses. Overall, 22 of the 25 students who completed the post-engagement survey recommended that the PBL forensic unit be used in the chemistry class in the following year.
Through the self-reflections conducted twice through the study, students considered the classroom norms that were addressed in the beginning of the unit. Most students felt they were practicing “putting ideas on the table” and “paying attention to others” well. These two classroom norms were two of the more common forms of collaboration that students practice regularly and therefore align with the high number of responses. The other three norms: pausing, paraphrasing, and posing questions, are collaboration elements that are not implemented into the classroom regularly. When students were asked which of the classroom norms they needed to work on more, it was not surprising to find that paraphrasing and pausing were two of the highest responses. Not only are these elements difficult to identify throughout conversation; they also require practice to do well. The most prevalent complaint through the surveys was that the groups felt split and students worked separately at difference paces than their group members. Most collaboration opportunities prior to this PBL study consist of students in smaller groups of 2-3. Working in groups of five or six was a new challenge for students and finding an effective way to keep the group working together seemed like a common challenge for students. For recommendations, a few students recommended smaller groups as they felt their discussion and participation improved when switching from their evidence collection group to their synthesis group. This student observation may be in part due to the jigsaw design and how the group expectations changed or it could be related to group size. Another student recommended to implement more collaboration opportunities throughout the school year for further practice in the outlined norms.

In the process of collecting field notes, students were seen more frequently practicing critical thinking skills as opposed to collaboration skills. Most common critical thinking skills were sharing ideas and generating questions as these techniques are more commonly practiced in
the current classroom as opposed to making connections and applying information to solve problems. Throughout the activity, students were most confident to elaborate on or clarify ideas. Summarizing a collection of ideas or regrouping were some of the other collaboration techniques observed throughout the collection of notes. In general, as the week progressed students became more engaged with their group. When the groups rearranged per the jigsaw design, the frequency of collaboration and critical thinking elements initially decreased as it took students time to get comfortable working with a new set of peers. However, by the end of both the evidence collection group and the synthesis groups, almost all students in both classes were working together well, staying on task the full duration of the period, and creating strong, evidence-based synthesis as a result.

The work of the four students selected as part of the motivation and achievement case study was reviewed individually to see the effect this PBL unit had on them. The highly motivated, high achieving student was initially not interested in the forensics activity at all. This student was upset with being required to work in a group and preferred to work independently on the assignment. During the study, though, this student quickly shifted their mindset and realized that sometimes more minds working toward the same goal can be beneficial as noted in their self-reflection. Through both the evidence collection group and synthesis group, this student was observed practicing delegation strategies and being aware of the overall tone of the group. If members were stressed or confused, this student would step up to suggest regrouping and collecting their ideas. Not only did this student work well in their evidence collection group, but appeared to enjoy it. They enthusiastically pointed out that they were doing science and were doing it well. The confidence observed by the student was due to their group solving a problem without a step-by-step procedure to follow and getting to collect data from samples themselves.
Overall, this student excelled in the content area addressed by the evidence collection group and did well to explain the evidence to their peers within the synthesis group. Because of a strong understanding from the first week, the final project from this student was well done and delivered well when presented to the audience.

For the student with high motivation and low achievement, this activity first appeared to be overwhelming. The student was quiet and insecure about their abilities. Many statements when working with their group indicated a lack of confidence in the first few days of the activity. This student identified that they needed to work on sharing ideas in the self-reflection, but did feel they were listening and paying attention to the group well. This student was in a group that was more divided than any of the other evidence collection groups in the study, but after the self-reflection this student began sharing more ideas and working to unite the group. This student, driven to do well, continuously shared their methods with the other members of the group and kept the teacher updated with group dynamic issues. Although the lack of unity among the group members was challenging, this student was able to practice several skills of collaboration that spanned beyond the initial ones laid out within the classroom norms. When students were rearranged into their synthesis groups, this student saw a better shift in group discussion and gained a confidence in sharing ideas. The jigsaw component aided in this student’s confidence because, in the synthesis group, they were the expert of the evidence collection assignment. Rather than being hesitant to share, this student was confident in the work from the original evidence collection group and did well explaining it to the other members of the group. Not only did this student pay attention to details throughout the activity, but being required to explain the material to peers reinforced understanding of the disciplinary core ideas. This student stated in
the second self-reflection that the group respected each other’s ideas which indicated a welcoming environment for positive collaboration.

The third student in the case study had low motivation to learn chemistry-related content and low achievement in the content area. This student initially struggled with the PBL forensic unit. This student’s confusion ultimately led to stress when they felt their group was working at a pace too fast for them to understand. However, through the student voice opportunity within PBL, this student shared their concern with the other group members. By advocating for themselves, the student had the opportunity to better understand the material and have a better interaction with their peers. Once this student spoke up, members of the group would further explain their work aloud until everyone understood the process. Keeping each member of the group engaged allowed for this student to feel comfortable and confident in sharing ideas. In particular, this student suggested the need for molar mass when calculating from percent compositions to chemical compounds. The other members of the group had not yet thought of this approach and praised this student for the suggestion. With the encouragement from the group during the evidence collection group, this student entered into the synthesis group much more confident in the material. As outlined in their first reflection this student went from needing to work on putting ideas on the table to struggling to pause for their peers to put ideas on the table in their second reflection. The comfort in discussing technical chemistry-related content significantly increased for this student from week one to week two and resulted in strengthening understanding of the disciplinary core ideas that were covered and being more confident in sharing their ideas.

The last student selected for the case study was a high achieving student but had low motivation to do well. This student understood the content quickly but was hesitant to put ideas
on the table as they were concerned about posing an idea that was incorrect. This fear of their peers’ perceptions resulted in the student spending the first couple days of the activity quietly observing. However, after the first self-reflection, this student did start to share ideas and work to keep the group on task together. This student would invite other students to engage who were struggling to stay on task. Not only were they working to involve others, but they were staying on topic themselves for the full duration of every class period. When this student switched to their synthesis group, they were able to confidently share out their findings from the evidence collection group and shared portions of their analysis with the group from their evidence collection packet. The use of data to support their claims was a useful tool for this student and ultimately resulted in a final project that exceeded the standards outlined in the grading rubric. This student incorporated more details from the evidence collection packets than any other synthesis group.
CONCLUSIONS & SUGGESTIONS

The PBL activity was a modified forensic unit from the National Science Teaching Association and it was implemented through a jigsaw classroom design. During this activity, students were able to practice innovative skills while reinforcing disciplinary core ideas of chemistry as outlined by the NGSS. This forensic unit, broken into three different sections, reinforced chemistry content such as density, gas laws, stoichiometry, acids and bases, along with an array of scientific practices. Unlike traditional teaching styles that rely on remembering and understanding information, PBL allows for students to apply and connect information to realistic applications. Through the evidence collection assignments and the final products, each of the groups supported this by producing work that exhibited a clear understanding of the disciplinary core ideas. Of the twenty-seven students who turned in their evidence collection packets on the last day of school, twenty-six students met or exceeded the standards. Twenty-eight of the thirty-one students who participated in the synthesis group presentations met the standards outlined in the PBL unit and exemplified a high level of understanding by evaluating evidence and creating a storyline through their connections. Each of the evidence collection groups was able to collect detailed information from the pieces of evidence and prompted questions provided to them. To produce the final assessment for the PBL unit, students were required to share their collected evidence with their peers and listen within their synthesis groups. Because of this, each synthesis group produced a final product that exceeded the standards of the PBL unit and used several sources of evidence to support their claim.

The student voice and choice component of problem-based learning promoted metacognition among the students and a more inclusive learning environment. Pairing the forensic unit with self-reflections allowed for students to identify collaboration elements that
they were performing well or those they needed to develop more fully. By having students reflect on their own strengths and weaknesses, students became aware of what to work on and showed improvement from the first week to the second week of the study. With the engagement survey supporting that students found the PBL to be more fun and meaningful than traditional classroom activities, students were more motivated to perform well. The overall interest in the real-world application resulted in students diving into the forensics case and working diligently in their groups for almost the full classroom time each day. During observations, students were heard discussing how much they enjoyed the unit and wished they did more activities like this. Students were also seen grabbing textbooks from the shelves or heading to the internet to learn more about the calculations they needed to do or the chemicals they were working with. The student interest was not only in solving the forensic case but in truly understanding the work they were doing.

The case study addressed how students of differing motivation and achievement levels were affected by the PBL activity. Initially higher achieving students were uninterested in the activity as they were preferring to do the work independently while the lower achieving students were initially quiet and not interested in participating in group discussion. However, as the study progressed, all four case study students began engaging with their groups more. The higher achieving students, student 1 and student 4 found value in having multiple people work toward a common goal and aimed to get all members of the group involved. The lower achieving students, student 2 and student 3, began advocating for themselves when confused and suggesting ideas when they had them. Both of the lower achieving students were able to contribute valuable information to their groups throughout the duration of the study.
Student participation and involvement did not seem to vary based on motivation. All four of the case study students, whether identified as low motivation or high motivation appeared to be fully engaged and interested in the activity through the duration of the study. All four case study students provided useful information and worked on practicing the collaboration skills labeled as classroom norms. The biggest factor in student participation appeared to be whether or not a student was introverted or extroverted. Students 2 and student 4 were more introverted whereas students 1 and 3 were more extroverted. Student 1 and 3 began contributing to their group from the first day where students 2 and 4 were initially quiet and took some time to warm-up to group collaboration. A valuable component for each of these four students and all the students in the study was the incorporation of the jigsaw design. The use of two groups, the first being an evidence collection group with the second being a synthesis group required each student to take the evidence found from their evidence collection group and share it with their synthesis group members. This process enabled every student to feel like an expert in their particular area and gave them the confidence to participate by sharing ideas and generating questions. The four case study students all had positive feedback regarding the dynamics of their synthesis groups.

The implementation of this PBL unit into the 11th grade classroom strengthened students’ understanding of chemistry content and resulted in the students operating at a higher order of thinking. The students not only had to remember and understand the disciplinary core ideas, but had to use these skills for data analysis and evaluate the data to make connections and apply it to solve problems. The forensic activity allowed for students to practice skills on collaboration, creativity, critical thinking and communication through the PBL design. The addition of self-reflections allowed for students to consider their own strengths and weaknesses and what skills they should spend more time on. Between the two self-reflections several students worked on
their weakest collaboration skill and noted improvement by the second week. Instilling the importance of motivation and metacognition into students while pairing it with chemistry content and skills strengthens students’ overall engagement and interest in the content. The engagement survey responses supported students enjoyed the forensic unit more than the general class format and 88% of students recommend the unit be used for the chemistry students next year.

The implementation of the jigsaw classroom technique allowed for additional benefits to the implementation of PBL. By having students work in two different groups throughout the study, students were required to listen critically when learning new material from their peers and present their own findings to the group. As shown in the Voyles et. al paper (2015), using a jigsaw classroom increases student accountability and reduces “social loafing” in group projects (Voyles et al., 2015). This pattern was exemplified throughout this study as each student among the evidence collection groups reinforced their knowledge of chemistry content and was able to solidify their understanding through higher order thinking. The sustained inquiry and authenticity within PBL activities allowed for students to apply their chemistry understanding to real-world problems while analyzing and evaluating the evidence they were collecting. Once evidence had been collected, the jigsaw classroom allowed students to share information with their peers and strengthen their ability to discuss technical information. Requiring students to create a final product connecting all the evidence to the overarching problem efficiently strengthened content retention. Not only did student participation improve through the jigsaw classroom as outlined in the Voyles et. al study, but the increase of empathy and compassion was also observed through this learning approach. As in the Aronson (2002) study, the jigsaw classroom supported students' compassion for others in the class. Through the self-reflections it was observed that throughout the duration of the study, several students were paying attention to the feelings of self and others.
In summary, the objective of this study was to determine the effects that PBL has on students’ content learning and the development of knowledge and skills in an 11th grade chemistry classroom. Through the evidence collection packets and the final assessments submitted by the students, it was clear that chemistry content was being reinforced through the activity and knowledge was applied at a higher operating level. As for other knowledge and skills, the field notes collected support students conducting collaborative and critical thinking strategies throughout the study. The creativity displayed in final projects presented by the synthesis groups also aligns with the innovative skills promoted through the PBL unit. Through the implementation of the jigsaw classroom and the classroom norms, students increased their accountability and their empathy for their peers throughout the activity. Students felt strongly about paying attention to self and others during the evidence collection group and were aware of their overall group dynamic when asked to reflect. The motivation and metacognition promoted by PBL was also displayed by the students throughout the study. This study considered the effectiveness of PBL for students of differing levels of motivation and achievement. Growth for all four of the case study students was observed both in their engagement with the activity and their skillset. Higher achieving students found value in providing further explanations to their group members and having additional inputs when working toward a common goal. Lower achieving students were seen to be gaining confidence through the activity and participating more among their groups. Overall, regardless of motivation, all four of the students were heavily engaged throughout the study.

**Suggestions & Limitations**

Implementing this PBL unit in the last three weeks of school posed some challenges as some students struggled to stay fully focused during the final days before summer vacation.
Along with the student fatigue, there was some pressure to complete the activity on time as there were only so many days left in the year. This unit is extremely valuable and may be better implemented earlier in the school year. The implementation of collaborative opportunities earlier in the year would give students more opportunities to practice these skills. The 2020-2021 school year also posed challenges as students were on a hybrid schedule due to the COVID-19 pandemic. The academic year consisted of students split into two cohorts in which they were in person two days a week and remote two days a week with a makeup day on Wednesdays. Chemistry class periods were eighty minutes during the first semester and became forty minutes in the second semester due to the hybrid scheduling. Along with the modified schedule, several students were also quarantined for 10-14 days at a time throughout the year. This hybrid schedule resulted in less material being covered, as a typical year consists of students having chemistry five days a week, alternating between eighty-minute and forty-minute periods.
REFERENCES


Kwietniewski, K., & Steve Macho, A. (2017). Secondary Education Commons, and the Vocational Education Commons Recommended Citation Kwietniewski, Katelyn. http://cte.buffalostate.edu/. Follow this and additional works at: http://digitalcommons.buffalostate.edu/careereducation_theses http://digitalcommons.buffalostate.edu/careereducation_theses/1


APPENDIX A: EVIDENCE COLLECTION ASSIGNMENTS

A.1 Cooler & Delivery Truck Evidence Collection Assignment

Name: ___________________________  Class: _______________  Date: __________

The Case of Kirsten K.:
The Cooler and Delivery Truck Evidence

Part I: The Cooler Evidence

Case Background

On September 4th, Kirsten K. went missing from the Bloomington-Normal area. A missing person’s report was filed by her husband, Larry J., and the police are still investigating. No sign of the body has been found yet, but police are currently investigating a lead and have narrowed their search down to four suspects. Police were informed that one of the suspects was seen taking a cooler to a recycling plant after allegedly dumping the body. When questioned, the manager of the recycling plant remembered a blue cooler being brought in sometime early in the week of September 7th. He remembers it for two reasons:

1. It had what looked like a bullet hole in it, and he remembers thinking “that it wouldn’t work very well as a cooler with a hole in it.”
2. The suspect was carrying a chain in the other hand when dropping off the cooler.

Police confiscated the recycled sample, which included pieces of the cooler and other items that were recycled with it. The recycled sample is currently en route to the CSI (Crime Scene Investigation) lab at the local police station. Police believe the suspect(s) stored the missing body inside of the cooler at one point in an attempt to dispose of the body in one of the following lakes: Lake Bloomington, Clinton Lake, or Lake Springfield. Police believe that the suspect(s) tried to recycle the evidence after failing to sink the cooler in one of these bodies of water.

Background Information on Lakes

Lake Bloomington—located just north of Bloomington, Illinois, this lake has a surface area of 635 acres and an average density of 0.98 g/mL. The smaller size of this lake allows for the water to change temperature more rapidly than the other lakes in the area. Therefore, the water in Lake Bloomington is, on average, warmer than in the other lakes. This means that less gas is dissolved in the water, making it slightly less dense than the average density of water.

Clinton Lake—located approximately 30 miles south of Bloomington, Illinois, this lake has a surface area of 4900 acres and an average density of 1.05 g/mL. The larger size of this lake means that the water temperature does not change as rapidly as smaller lakes. Therefore, the water in Clinton Lake is, on average, cooler than in the other lakes. This allows for more gas to be dissolved in the water, making it denser than the average density of water.

Lake Springfield—located approximately 50 miles south of Bloomington, Illinois, this lake has a surface area of 4234 acres and an average density of 1.01 g/mL. The lake is of average size and of average temperature.
Purpose

Your investigation should help police to determine the following three questions:

1. What is the density range of the cooler in which the suspect(s) tried to store the missing body?
2. In which body of water should police start looking for the body?
3. Would the suspect(s) have been successful in trying to dispose of the body, by sinking it in the cooler using the methods described?

Hypothesis

In which scenarios (ex. bullet holes, chains, filling with water) would the suspect(s) have been successful or unsuccessful in sinking the cooler? Address all scenarios in your hypothesis.

Procedure

Write out your experimental procedure (numbered list of steps) below. Be specific!!

Materials

- Various liquids of varying densities
- Recycled sample
- Small dishes
- Spoons

Data

Construct a data table or tables to collect data as described in the procedure.
Analysis-Calculation

There are three key questions that police must address in order to verify or refute the evidence from the cooler:
1. Would the body have actually fit inside the cooler?
2. Would the cooler have even been able to float with the body inside?
3. Would the cooler have floated with a bullet hole in it that would have allowed water to fill the cooler?

Answer the questions below, which will help to answer these three key questions. Address these three questions in your conclusion and support them with the calculations below:

1. The igloo cooler that was used in this case was believed to have had the labeled capacity of 162 quarts. Kirsten K.’s body had a volume of approximately 59.5 L (0.95 L = 1 quart). Would the body have even fit in the cooler? Show work to support your answer.

2. The cooler was believed to have had dimensions of 104 cm long, 45.7 cm wide, and 53.3 cm deep. If the cooler sinks one centimeter, calculate the volume of water it displaces.

3. The density of lake water where you determined police should start their investigation is _______ g/cm³. Calculate the mass in kilograms of the lake water displaced by the volume you calculated in question #2. (1000 grams = 1 kilogram)

4. Kirsten K.’s body weighed 128 pounds. The empty cooler has a mass of 13.6 kg, and the chain that police believed the suspect wrapped around the cooler to try to make it sink, has a mass of 13.6 kg as well. Calculate the total mass of the body, the cooler, and the chain. Using your calculation from question #3, how many centimeters will the cooler with the body wrapped in
chains sink? Will the cooler be completely submerged below the surface of the water? (1 kg = 2.21 lbs)

5. Now let's determine if the cooler will still float if you shoot a hole in it and allow water to enter. Let's consider the extreme case in which water fills the entire cooler (which it won't). The inside dimensions of the cooler are 35.5 cm by 94.0 cm by 43.2 cm deep. Calculate the inside volume of the cooler in liters. (1 mL = 1 cm³)

6. Calculate the mass of lake/creek water that would completely fill the cooler. Remember to use the density of lake/creek water you found in the Cooler Evidence.

7. Calculate the total mass of the cooler, chain, and lake/creek water. How many centimeters will the cooler sink? Will it be completely submerged if it is full of lake/creek water?

Conclusion

In which body of water should the police start their investigation and what specific data supports this? Be sure to refer back to your hypothesis.
Discussion

1. Describe the likelihood of the body being able to fit inside the cooler. Use calculations to support your answer.

2. Describe the ways in which the suspects tried to dispose of the cooler. Were they successful? Support your statement with evidence.

3. Describe what effect the bullet hole would have had on the ability of the color to sink in the lake.

Part II: The Delivery Truck Evidence

Background Information About Airbags

A sensor in front of the car detects the sudden deceleration and sends a signal to a cylinder containing a mixture of chemicals. In the cylinder, an igniter goes off, starting a series of chemical reactions that release a large volume of nitrogen gas. The bag literally bursts from its storage site at up to 200 mph. When the airbag deploys, the maximum volume it can hold is 65 Liters. The gas fills the airbag, and you hit the soft bag instead of the steering wheel or dashboard. A second later the gas quickly dissipates through tiny holes in the bag, thus deflating the bag so you can move. The bag has to inflate in less than a tenth of a second, and it has to inflate with exactly the right amount of gas. If it under-inflates, it would not provide enough protection; if it over-inflates, it might rupture or cause an explosion.

The first reaction set off by the igniter is the decomposition of sodium azide into sodium metal and nitrogen gas.

\[ 2\text{NaN}_3 \rightarrow 2\text{Na} + 3\text{N}_2 \]

By itself, this reaction cannot fill the airbag fast enough, and the sodium metal that is produced is dangerously reactive. To solve these problems, engineers included potassium nitrate in the mixture of reactants. The potassium nitrate reacts with the sodium produced in the first reaction, releasing even more nitrogen gas.

\[ 10\text{Na} + 2\text{KNO}_3 \rightarrow \text{K}_2\text{O} + 5\text{Na}_2\text{O} + \text{N}_2 \]
The heat released by this reaction raises the temperature of the gaseous product, helping the bag inflate even faster. The heat causes all the solid reaction products to fuse together with SiO₂, powdered sand, which is also part of the reaction mixture.

Background Information About the Case

Police have started searching Clinton Lake, as you suggested, looking for evidence regarding the missing person’s report they received for Kirsten K. Police have found an abandoned delivery truck at the bottom of the lake, which may hold evidence that could lead to finding the person(s) responsible for the kidnapping of Kirsten K. The airbag has been deployed, but there was a malfunction and the airbag remained deployed even after entering the lake. Police want to make sure the airbag will not explode as they lift the truck up from the bottom of the lake to the surface in order to preserve all possible evidence in the delivery truck that has not yet been destroyed. They have asked you to help collect evidence and double check some of the data they have already taken.

Purpose

To determine if the vehicle can be safely removed from the lake without the airbag exploding.

Hypothesis

Looking at the data provided by the police about the depth, temperature, and pressure of the lake, predict what will happen to the volume of the airbag as the truck is removed from the bottom of Clinton Lake. Consider the Pressure (P), Temperature (T), and Volume (V) relationships as well when giving your prediction.

Data

Below is the lake data from the police including the depths, temperatures, and pressures to help you determine the volume of the airbag at various depths.

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>Temperature (°C)</th>
<th>Pressure Calculated</th>
<th>Volume (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>5</td>
<td>2.24 atm</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>10</td>
<td>1520 mmHg</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>15</td>
<td>1140 mmHg</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>1.07 atm</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>22</td>
<td>1.01 atm</td>
<td></td>
</tr>
</tbody>
</table>
Analysis—Graphing

Before you arrived at the scene, police started to collect data about the temperature, pressure, and volume to try to gain more information about the abandoned vehicle.

Graph #1: Pressure vs. Volume
Graph the pressure from the lake versus the volume to show the relationship between the two variables.
**Graph #2: Volume vs. Temperature**

Graph the volume that you calculated for each of the various temperatures in the lake to show the relationship between the two variables. (**You will not be able to create this graph until after you do the Analysis—calculations section of the assessment.**)

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Analysis—Calculations**

You have been hired by the police as a chemical engineer responsible for investigating the abandoned vehicle found with a deployed airbag. For police to gain insight into the case, they need you to calculate if the delivery truck can be safely removed from the lake without the airbag expanding too much, bursting, and destroying evidence.

1. Calculate the number of moles of gas in the airbag at maximum volume, 65 liters, at room temperature, 25°C, and at 1 atmosphere (atm) of pressure.
2. Calculate the volume at the various depths given by the police to determine if the airbag will expand to a volume greater enough to make it explode.

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Volume Calculations using Ideal Gas Law</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Conclusion

Explain to the police whether or not they will be able to gather evidence from the delivery truck and why, based on your calculations.

Discussion Questions

1. According to volume data, will the police be able to retrieve evidence from the delivery truck after retrieving the truck from the lake? Explain.

2. Describe the pressure versus volume graph. Use the words direct or inverse in your description of the relationship, along with data from the graph, in your answer to describe which gas law this graph represents.

3. Describe the volume versus temperature graph. Use the words direct or inverse in your description of the relationship, along with data from the graph, in your answer to describe which gas law this graph represents.

4. Using the ideas supporting the kinetic molecular theory, explain why the number of moles of gas in the deployed airbag would stay the same throughout the volume calculations.
The Case of Kirsten K.:  
The Chemical and Crime Scene Evidence

Part I: Chemical Evidence

1.A The Delivery Truck and Crime Scene Evidence

Case Background

Police have scanned the area, and you have been called to do further tests on samples found from what police believe to be the crime scene (even though the victim’s body has not yet been found) to present new information about the victim and suspects. After analyzing the crime scene samples, you have found what could be important chemical evidence that may link the suspects to the crime scene. There were five distinct residues that were found and the percentage of each element found in them is listed below in Table 1.

<table>
<thead>
<tr>
<th>Abandoned Delivery Truck</th>
<th>C</th>
<th>H</th>
<th>N</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemical A</strong></td>
<td>63.15%</td>
<td>5.30%</td>
<td>---</td>
<td>31.55%</td>
</tr>
<tr>
<td><strong>Chemical B</strong></td>
<td>63.15%</td>
<td>5.30%</td>
<td>---</td>
<td>31.55%</td>
</tr>
<tr>
<td><strong>Chemical C</strong></td>
<td>67.31%</td>
<td>6.98%</td>
<td>4.62%</td>
<td>21.10%</td>
</tr>
<tr>
<td><strong>Chemical D</strong></td>
<td>60.00%</td>
<td>4.48%</td>
<td>---</td>
<td>35.53%</td>
</tr>
<tr>
<td><strong>Chemical E</strong></td>
<td>49.48%</td>
<td>5.15%</td>
<td>28.87%</td>
<td>16.50%</td>
</tr>
</tbody>
</table>

Table 1: Percentage of each Element found from the Chemical Evidence

Purpose

Your investigation should help police to determine if the chemical analysis matches any of the suspects to the crime scene and how they may or may not be linked.

Procedure

Use the information provided to complete the following steps:

1. From the percentages listed in Table 1, find the formula for each of the Chemicals A-E.
2. Using Table 2 below and the percent compositions given in Table 1, determine the chemicals found on the victim.
3. If no match can be found, mark the chemical as unknown.

Data

**Table 2: Possible Compounds Matches**

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Chemical Formula</th>
<th>Everyday Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaminophen</td>
<td>C₈H₁₀NO₂</td>
<td>Painkiller (Tylenol)</td>
</tr>
<tr>
<td>Almond</td>
<td>C₃H₅O</td>
<td>Flavoring</td>
</tr>
<tr>
<td>Aspartame</td>
<td>C₉H₁₈N₂O₉</td>
<td>Artificial sweetener</td>
</tr>
<tr>
<td>Aspirin</td>
<td>C₈H₉O₄</td>
<td>Pain killer</td>
</tr>
<tr>
<td>Caffeine</td>
<td>C₉H₅N₂O</td>
<td>Low-level stimulant</td>
</tr>
<tr>
<td>Cocaine</td>
<td>C₁₅H₂₁NO₆</td>
<td>Narcotic, illegal</td>
</tr>
<tr>
<td>Codeine</td>
<td>C₁₃H₂₁NO₃</td>
<td>Painkiller, prescription controlled</td>
</tr>
<tr>
<td>Curare</td>
<td>C₁₃H₂₈N₂O</td>
<td>Poison</td>
</tr>
<tr>
<td>Ibuprofen</td>
<td>C₁₃H₁₈O₂</td>
<td>Pain killer</td>
</tr>
<tr>
<td>Nitroglycerine</td>
<td>C₈H₁₈N₃O₉</td>
<td>Explosive, heart medication</td>
</tr>
<tr>
<td>Trinitrotoluene</td>
<td>C₈H₇N₃O₆</td>
<td>Explosive (TNT-dynamite)</td>
</tr>
<tr>
<td>Vanilla</td>
<td>C₄H₄O₃</td>
<td>Flavoring</td>
</tr>
</tbody>
</table>

**Analysis-Calculation**

1. Show calculations for finding the chemical formula for each compound:

   Chemical A: ____________________

   Chemical B: ____________________

   Chemical C: ____________________
Chemical D: 

Chemical E: 

2. Calculate the empirical formula for any unknown substances:

Conclusion

List each of the chemicals and explain why you might expect to find each of these chemicals at the crime scene. This information should be based on the location of the crime scene given to police based on the evidence collected in the previous assessment.

1.B The Suspect Evidence

Background Information

Subsequent chemical analysis of clothing, blood, and skin samples from the four suspects and a piece of clothing believed to have belonged to the victim revealed the following information provided in Table 3.

Data

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>H</th>
<th>N</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victim</td>
<td>63.15%</td>
<td>5.30%</td>
<td>---</td>
<td>31.55%</td>
</tr>
<tr>
<td>Suspect #1</td>
<td>60.00%</td>
<td>4.48%</td>
<td>---</td>
<td>35.53%</td>
</tr>
<tr>
<td>Suspect #2</td>
<td>67.31%</td>
<td>6.98%</td>
<td>4.62%</td>
<td>21.10%</td>
</tr>
<tr>
<td>-----------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Suspect #3</td>
<td>32.43%</td>
<td>2.70%</td>
<td>---</td>
<td>64.87%</td>
</tr>
<tr>
<td>Suspect #4</td>
<td>63.56%</td>
<td>6.00%</td>
<td>9.27%</td>
<td>21.77%</td>
</tr>
<tr>
<td>Suspect #4</td>
<td>15.87%</td>
<td>2.22%</td>
<td>18.15%</td>
<td>63.41%</td>
</tr>
<tr>
<td>Suspect #4</td>
<td>49.48%</td>
<td>5.15%</td>
<td>28.87%</td>
<td>16.50%</td>
</tr>
</tbody>
</table>

**Analysis**

1. Show calculations for each of the chemicals found for each of the suspects below:

   **Victim:**
   
   **Suspect #1:**
   
   **Suspect #2:**
   
   **Suspect #3:**
   
   **Suspect #4:**

2. Calculate the empirical formula for any unknown substances:

**Conclusion**

Determine if there is a connection between the chemicals found on the suspects in Part I.B and the information gained from the chemical analysis in Part I.A.
Which chemicals were you unable to identify? What does having an unknown mean for the investigation?

I.C: The Cake Shop Ingredients Analysis

Background Information

After analyzing the chemicals further, it has been determined that some of the chemicals found at the crime scene (where the victim was believed to have been at one point) and on suspect #3 could have derived from the cake shop where both were employed. Further investigation shows that the day before the murder, the victim and suspect #3 were fully booked with requests for wedding cakes.

Data

The cake shop, in order to keep their recipes secret, synthesizes their own vanilla flavoring for their cakes based on the following reaction:

$$\text{C}_2\text{H}_4\text{O}_2 + \text{C}_2\text{H}_3\text{O}_3 \rightarrow \text{C}_4\text{H}_6\text{O}_3 + \text{H}_2\text{O}$$

(guaiacol) (glyoxylic acid) (vanilla)

To verify the reaction done in the cake shop, the CSI chemical lab has simulated the experiment. They used 4.2 grams of guaiacol and 6.8 grams of glyoxylic acid.

Analysis

Using the information given, do the following calculations:

1. Show the balanced equation below.

2. Determine the limiting reactant.

3. Determine the theoretical yield of vanilla.

4. A 4.85 gram sample of vanilla was produced from the reaction in the CSI chemical lab. Based on this information, calculate the % yield by comparing the experimental amount to the theoretical amount.
5. Does the chemical % composition of the excess reagent match any of the unknowns from part one or part two? If so, identify the unknown(s).

Conclusion

Determine the connection, if any, between the unknowns and the crime scene. What else can you conclude about the case from the evidence presented through the calculations and from the new suspect information?

Part II: Crime Scene Evidence

II.A Crime Scene Soil Sample Evidence

Case Background

Finally, with your help, police were able to find the body of the victim, Kirsten K., and now consider this a murder investigation. Police have gathered evidence from the crime scene, including clothing, soil samples, and a firearm found near the crime scene. A medical tracer was also found in the victim’s body which should help put a timeline and a cause of death to the disappearance and the murder of Kirsten K. Shoes were collected from each of the suspects’ homes along with the shoes from the victim’s body and taken to the lab for the sample composition be analyzed and compared to the soil around the crime scene. Police are hoping that this evidence will narrow the suspect list down to those suspects who specifically had this specific soil composition in the sample on their shoes.

Purpose

To use the composition of the soil samples from the suspects’ shoes to match the crime scene sample.

Procedure

1. Prepare the soil samples taken from each suspect’s shoe and from the crime scene on microscopic slides.
2. Set the microscope lens to an appropriate magnification to complete the qualitative qualities of the soil.
3. Sketch the view you observe through the microscope eyepiece for each of the 4 samples from each of the 4 suspects in a data table in the data section.

**Materials**
- Microscope
- Microscope Slides
- Microscope Slide Covers

**Data**

**Table #1: Comparison of Crime Scene Samples**
Create sketches in the circles below to record the soil composition from each of the suspect samples in the data table format.

<table>
<thead>
<tr>
<th>Suspect Sample</th>
<th>Microscopic View</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample: Crime Scene Soil Sample</td>
<td></td>
</tr>
<tr>
<td>Magnification:</td>
<td></td>
</tr>
<tr>
<td>Observations:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample:</td>
<td></td>
</tr>
<tr>
<td>Magnification:</td>
<td></td>
</tr>
<tr>
<td>Observations:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

Which of the suspects were present at the crime scene? How did the qualitative data from the microscopic view help determine the suspects who were or were not present? Who are the lead suspects currently and why?
The Case of Kirsten K.:  
The Weapon and Blood Stain Evidence

Part 1: Fingerprint Analysis

Case Background

A gun was found at the crime scene next to the victim with the handle wrapped in aluminum foil. The police need your help to collect and analyze the fingerprints found on the aluminum foil handle to determine if the prints match any of the suspects and/or victim. Samples from the gun handle are ready for analysis.

Background Information on Fingerprint Classification

Latent prints cannot be seen by the naked eye and often must be dusted in order to see the patterns more clearly. Every person has a unique set of fingerprints, but three basic patterns allow forensic scientists to classify them. The three basic patterns are the whorl, the arch, and the loop. Whorl patterns have lots of circles that do not leave either side of the print. Arch patterns have lines that start on one side of the print, rise toward the center, and leave on the other side of the print. Loop patterns have lines that start on one side of the print, rise toward the center, turn back, and leave on the same side from which they started. Fingerprints are permanent; they form during fetal development and start in the basal layer of the skin. Fingerprints always grow in the same place and any damage to the basal layer becomes permanent.

[Diagram of fingerprint patterns: Arch, Tentarch, Loop, Double Loop, Pocked loop, Whorl, Mixed]
Procedure

1. Examine the print first on the aluminum sample before dusting to identify whose print it most closely matches based on the prints in the evidence envelope.

2. Dust the fingerprints with the powder and brushes provided. Be careful not to destroy the print when dusting with the brush.

3. After dusting the print with the brush, preserve the print by placing the clear tape over the dusted print on the aluminum foil.

4. Try to match the print to the suspect/victim prints in the evidence envelope.

Materials

- Dusting powder and brushes
- Fingerprint samples
- Clear tape
- White paper

Data

Construct a table to identify which types of fingerprints are on the gun handle and to whom the prints belong from the suspect list.
Conclusion

1. Who are the possible matches to the fingerprints on the aluminum foil handle?

2. Are there any suspects that can be ruled out at this point for the murders of Kirsten K.? Explain.

Part II: Blood Stain Analysis

Background Information

Clothes from each of the suspects and victim have been taken to determine if the stains found on the clothes are blood stains. Your job is to determine which clothing items contain blood and identify the stains that are not blood.

Data—Part A

Each of the blood stains must fall within a pH range of 6.5-8.0 to be considered actual human blood. For each of the following pieces of data, calculate the pH from the information given. If the stain believed to be blood is too small, only the [OH⁻] concentration could be obtained. If the sample believed to be blood is large enough, the [H₃O⁺] concentration could be obtained. To calculate pH, use the following equations:

\[
\text{pH Calculation Equations}\\
\text{pH} = -\log[H_3O^+]\\
\text{pOH} = -\log[OH^-]\\
\text{pH} + \text{pOH} = 14
\]
### Table 1: pH Ranges Calculations to Determine Blood Stains

<table>
<thead>
<tr>
<th>Suspect Information</th>
<th>[H$_3$O$^+$] (concentrations listed for the number of stains found)</th>
<th>[OH$^-$]</th>
<th>pH</th>
<th>Blood Stain: Yes or No?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victim: Kristen K.</td>
<td>(1)$1.00 \times 10^{-7}$ M</td>
<td>--------</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>Suspect #1:</td>
<td>--------</td>
<td>(1)$3.16 \times 10^{-8}$ M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspect #2:</td>
<td>--------</td>
<td>(1)$3.16 \times 10^{-7}$ M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspect #3:</td>
<td>--------</td>
<td>(1)$1.00 \times 10^{-10}$ M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspect #4: New Victim:</td>
<td>(1)$3.16 \times 10^{-7}$ M</td>
<td>(2)$3.16 \times 10^{-8}$ M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspect #5:</td>
<td>--------</td>
<td>(1)$3.16 \times 10^{-7}$ M</td>
<td>(2)$1.00 \times 10^{-7}$ M</td>
<td>(3)$3.16 \times 10^{-8}$ M</td>
</tr>
</tbody>
</table>

**Analysis—Calculations Part A**

Show the work below for the calculations to fill in Table 1 above.
Data—Part B

Further tests have been done on the stains that were proven to fall into the pH range matching the pH of blood from 6.5-8.0. More than one stain may have been found on more than one piece of clothing. Tests were done to see if the pH values that were calculated in Table 1 match any of the blood types from each of the suspects who were found to have blood on them.

Table 2: Blood Types and pH’s

<table>
<thead>
<tr>
<th>Blood Type</th>
<th>pH Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8.0</td>
</tr>
<tr>
<td>B</td>
<td>7.0</td>
</tr>
<tr>
<td>AB</td>
<td>7.5</td>
</tr>
<tr>
<td>O</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Table 3: Blood Types of Suspects and Victim

<table>
<thead>
<tr>
<th>Blood Type</th>
<th>pH Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victim</td>
<td>B</td>
</tr>
<tr>
<td>Suspect #1</td>
<td>A</td>
</tr>
<tr>
<td>Suspect #2</td>
<td>A</td>
</tr>
<tr>
<td>Suspect #3</td>
<td>AB</td>
</tr>
<tr>
<td>Suspect #4</td>
<td>O</td>
</tr>
<tr>
<td>Suspect #5</td>
<td>AB</td>
</tr>
</tbody>
</table>

Table 4: Blood pH Matching

<table>
<thead>
<tr>
<th>Suspect Information</th>
<th>[H₂O⁺] of blood sample 1</th>
<th>[H₂O⁺] of blood sample 2</th>
<th>[H₂O⁺] of blood sample 3</th>
<th>Suspect/Victim Matches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victim</td>
<td>1.00 x 10⁻² M</td>
<td>------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>Suspect #2</td>
<td>$3.16 \times 10^{-8}$ M</td>
<td>------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>Suspect #4</td>
<td>$3.16 \times 10^{-7}$ M</td>
<td>$3.16 \times 10^{-8}$ M</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>Suspect #5</td>
<td>$3.16 \times 10^{-7}$ M</td>
<td>$1.00 \times 10^{-7}$ M</td>
<td>$3.16 \times 10^{-8}$ M</td>
<td></td>
</tr>
</tbody>
</table>

**Analysis—Calculations Part B**

1. Calculate the pH of each of the samples from Table 4 to see which ones match the blood types provided in Table 2 and Table 3.

**Conclusion**

1. Which of the suspects and/or victims had stains that fell into the pH range of blood? (from Table 1)

2. Why may have Harold shown a basic stain and Elizabeth have shown an acidic stain? You may have to look back at previous assessments and/or suspect files.
3. After further calculations for those suspects with blood stains, which of the suspects/victims did those stains prove to be a match to? (from Table 4)

4. What are possible scenarios to link the murderer to Kristen K.? Is there more than one suspect who could be responsible for the murder? Does the evidence lead one way or another?
## A.4 Evidence Collection Packet Rubric

### GRADING RUBRIC A

<table>
<thead>
<tr>
<th>Name:</th>
<th>Score /60</th>
<th>______ %</th>
<th>Grade:</th>
</tr>
</thead>
</table>

#### I. Introduction

<table>
<thead>
<tr>
<th>Application</th>
<th>wgt</th>
<th>Exemplary</th>
<th>At Standard</th>
<th>In Progress</th>
<th>Still Emerging</th>
<th>No Evaluation</th>
</tr>
</thead>
</table>
| Defining Problems | 1a | ½ | Makes insightful connections between ideas or events that might not be obvious—abstract thinking evident (4 of 4)  
- Background information includes highlighted information about both the cooler and delivery truck cases and the suspect files that are relevant to answering the purpose  
- Purpose is clearly stated and correct  
- A hypothesis is given for both the cooler evidence testing and the delivery truck gas laws data  
- Procedure supports purpose with a detailed, numerical list of steps for developing a density gradient for the cooler evidence | Makes general, logical connections between ideas or events; mostly concrete in nature (3 of 4) | Makes superficial connection between ideas; thinking might be confused or incomplete (2 of 4) | Makes incorrect or no connections between ideas (1 of 4) | No work shown for this section |

#### II. Data—Part I: The Cooler Evidence

<table>
<thead>
<tr>
<th>Application</th>
<th>wgt</th>
<th>Exemplary</th>
<th>At Standard</th>
<th>In Progress</th>
<th>Still Emerging</th>
<th>No Evaluation</th>
</tr>
</thead>
</table>
| Interpreting Models | 1b | ½ | Interprets visuals or models at a complex level (4 of 4)  
- Sufficient number of trials to obtain meaningful density data for each liquid sample with the blue cooler pieces  
- All qualitative measurements are accurately recorded in a data table format, not just listed  
- Completed data table includes a relevant table explaining the data sets  
- Correct labels/units are used for the qualitative data | Interprets visuals or models at a general level (3 of 4) | Interpretation of visual or model contains errors that restrict understanding (2 of 4) | Shows fundamental errors in use and understanding of visual (1 of 4) | No work turned in for this section |

#### II. Data—Part II: The Delivery Truck Evidence

<table>
<thead>
<tr>
<th>Application</th>
<th>wgt</th>
<th>Exemplary</th>
<th>At Standard</th>
<th>In Progress</th>
<th>Still Emerging</th>
<th>No Evaluation</th>
</tr>
</thead>
</table>
| Interpreting Models | 1b | ½ | Interprets visuals or models at a complex level (4 of 4)  
- The calculated volume for each depth is shown in a data table format  
- All calculated measurements for converting the mffig to atm are shown within the data table, not just listed  
- Completed data table includes a relevant table explaining the data sets  
- Correct labels/units are used for both the qualitative and quantitative data | Interprets visuals or models at a general level (3 of 4) | Interpretation of visual or model contains errors that restrict understanding (2 of 4) | Shows fundamental errors in use and understanding of visual (1 of 4) | No work turned in for this section |
### III. Analysis: Graph—Part II: The Delivery Truck Evidence

<table>
<thead>
<tr>
<th>Application</th>
<th>#</th>
<th>wgt</th>
<th>Exemplary</th>
<th>At Standard</th>
<th>In Progress</th>
<th>Still Emerging</th>
<th>No Evaluation</th>
</tr>
</thead>
</table>
| Interpreting Models | 1h | ½ | Interprets visuals or models at a complex level (4 of 4)  
- Points are plotted correctly on both of the gas law graphs and even intervals are shown on both axes of the graph  
- A best fit line is correctly drawn for each of the graphs for both relationships  
- Complete graphs include a relevant use of data sets  
- Correct labels and units are used for both the x and y-axis | Interprets visuals or models at a general level (3 of 4)  
Interpretation of visuals or models contains errors that restrict understanding (2 of 4)  
Shows fundamental errors in use and understanding of visuals (1 of 4) | No work turned in for this section |

### III. Analysis: Calculations—Part I: The Cooler Evidence

<table>
<thead>
<tr>
<th>Application</th>
<th>#</th>
<th>wgt</th>
<th>Exemplary</th>
<th>At Standard</th>
<th>In Progress</th>
<th>Still Emerging</th>
<th>No Evaluation</th>
</tr>
</thead>
</table>
| Problem Calculations | 2a | ½ | All essential information is evident through well-organized work while justifying the solution (4 of 4)  
- Calculations (2-5) for proving discussion question 1 are complete, correct, and all work was shown including units for all numbers throughout calculation  
- Calculations (2-6, 3-4) for proving discussion question 2 are complete, correct, and all work was shown including units for all numbers throughout calculation  
- Calculations (4-5, 7) for proving discussion question 3 are complete, correct, and all work was shown including units for all numbers throughout calculation  
- Significant figures are considered when writing final answers for each of the calculations | Most essential information is evident through organized work while leading to the solution (3 of 4)  
Minimum information is evident through organized work with a solution present (2 of 4)  
Work is extremely unorganized with no solution present (1 of 4) | No work shown for this section |

### III. Analysis: Calculations—Part II: The Delivery Truck Evidence

<table>
<thead>
<tr>
<th>Application</th>
<th>#</th>
<th>wgt</th>
<th>Exemplary</th>
<th>At Standard</th>
<th>In Progress</th>
<th>Still Emerging</th>
<th>No Evaluation</th>
</tr>
</thead>
</table>
| Problem Calculations | 2a | ½ | All essential information is evident through well-organized work while justifying the solution (4 of 4)  
- The correct conversion was shown for the gas law that was used for calculating the number of moles of gas in the airbag and the volume at each of the depths  
- Calculations for the number of moles of gas in the airbag are complete, correct, and all work was shown  
- Calculations for the volume of the airbag at various depths are complete, correct, and all work was shown  
- Units for ALL numbers were consistently used throughout the calculations in this section | Most essential information is evident through organized work while leading to the solution (3 of 4)  
Minimum information is evident through organized work with a solution present (2 of 4)  
Work is extremely unorganized with no solution present (1 of 4) | No work shown for this section |
### IV. Conclusion—Part 1: The Cooler Evidence

<table>
<thead>
<tr>
<th>Application</th>
<th># wgt</th>
<th>Exemplary</th>
<th>At Standard</th>
<th>In Progress</th>
<th>Still Emerging</th>
<th>No Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connecting Ideas</td>
<td>1d 1/2</td>
<td>Makes insightful connections between ideas or events that might not be obvious—abstract thinking evident (4 of 4).&lt;br&gt;• The purpose is answered for which lake police should start looking around to find more evidence and designate a crime scene.&lt;br&gt;• Specific data (evidence) from the density gradient lab work is used to support the lake choice.&lt;br&gt;• Evidence to support or not support the hypothesis for the cooler evidence uses specific examples from the data.&lt;br&gt;• Where is the evidence leading so far? Any suspects more likely than others at this point based on the evidence and suspect file information? Make sure you say why!</td>
<td>Makes general, logical connections between ideas or events; mostly concrete in nature (3 of 4)</td>
<td>Makes superficial connections between ideas; thinking might be confused or incomplete (2 of 4)</td>
<td>Makes incorrect or no connections between ideas (1 of 4)</td>
<td>No work shown for this section</td>
</tr>
</tbody>
</table>

### IV. Conclusion—Part II: The Delivery Truck Evidence

<table>
<thead>
<tr>
<th>Application</th>
<th># wgt</th>
<th>Exemplary</th>
<th>At Standard</th>
<th>In Progress</th>
<th>Still Emerging</th>
<th>No Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connecting Ideas</td>
<td>1d 1/2</td>
<td>Makes insightful connections between ideas or events that might not be obvious—abstract thinking evident (4 of 4).&lt;br&gt;• The purpose is answered for if the police will be able to safely extract the sunken delivery truck from the lake without the volume of the airbug going over the maximum capacity.&lt;br&gt;• Specific data (evidence) is used to support the whether or not the airbug will stay intact when the truck is retrieved from the lake.&lt;br&gt;• Evidence to support or not support the hypothesis for the delivery truck evidence uses specific examples from the data.&lt;br&gt;• Where is the evidence leading so far? Any suspects more likely than others at this point based on the evidence and suspect file information? Make sure you say why!</td>
<td>Makes general, logical connections between ideas or events; mostly concrete in nature (3 of 4)</td>
<td>Makes superficial connections between ideas; thinking might be confused or incomplete (2 of 4)</td>
<td>Makes incorrect or no connections between ideas (1 of 4)</td>
<td>No work shown for this section</td>
</tr>
</tbody>
</table>

### V. Discussion Questions—Part 1: The Cooler Evidence

<table>
<thead>
<tr>
<th>Application</th>
<th># wgt</th>
<th>Exemplary</th>
<th>At Standard</th>
<th>In Progress</th>
<th>Still Emerging</th>
<th>No Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supporting Ideas</td>
<td>3b 1/2</td>
<td>Support used is varied, the best available, and strongly enhances audience understanding (4 of 4).&lt;br&gt;• Questions #1 is answered correctly and answer is supported with data to explain why.&lt;br&gt;• Questions #2 is answered correctly and answer is supported with data to explain why.&lt;br&gt;• Questions #3 is answered correctly and answer is supported with data to explain why.&lt;br&gt;• Answers are written in complete sentences for all questions that require explanations</td>
<td>Support is accurate and sufficiently detailed—all basics evident (3 of 4)</td>
<td>Support is insufficient, inaccurate, or vague in places—enough to confuse audience somewhat (2 of 4)</td>
<td>Support is missing, inaccurate, or vague overall (1 of 4)</td>
<td>No work shown for this section</td>
</tr>
</tbody>
</table>
### V. Discussion Questions—Part II: The Delivery Truck Evidence

<table>
<thead>
<tr>
<th>Application</th>
<th>#</th>
<th>wgt</th>
<th>Exemplary (10)</th>
<th>At Standard (8)</th>
<th>In Progress (7)</th>
<th>Still Emerging (6)</th>
<th>No Evaluation (0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supporting Ideas</td>
<td>3b</td>
<td>½</td>
<td>Support used is varied, the best available, and strongly enhances audience understanding (4 of 4)</td>
<td>Support is accurate and sufficiently detailed—all basics evident (3 of 4)</td>
<td>Support is insufficient, inaccurate, or vague in places—enough to confuse audience somewhat (2 of 4)</td>
<td>Support is missing, inaccurate, or vague overall (1 of 4)</td>
<td>No work shown for this section</td>
</tr>
</tbody>
</table>

#### Overall Evidence Report Formatting

<table>
<thead>
<tr>
<th>Application</th>
<th>#</th>
<th>wgt</th>
<th>Exemplary (10)</th>
<th>At Standard (8)</th>
<th>In Progress (7)</th>
<th>Still Emerging (6)</th>
<th>No Evaluation (0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>1c</td>
<td>½</td>
<td>Technology used is best available and appropriate for the required research, data representation, interpretation, and communication of results. (4 of 4)</td>
<td>Technology was used for the required research, data representation, interpretation, and communication of results. (3 of 4)</td>
<td>Technology used was insufficient for the required research, data representation, interpretation, and communication of results. (2 of 4)</td>
<td>Evidence of Technology use is missing and/or insufficient (1 of 4)</td>
<td>No work shown for this section</td>
</tr>
</tbody>
</table>

#### Content Recall

<table>
<thead>
<tr>
<th>Application</th>
<th>#</th>
<th>wgt</th>
<th>Exemplary (10)</th>
<th>At Standard (8)</th>
<th>In Progress (7)</th>
<th>Still Emerging (6)</th>
<th>No Evaluation (0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content Recall</td>
<td>1F</td>
<td>½</td>
<td>Recalls virtually all essential terms and factual information</td>
<td>Recalls most essential terms and factual information</td>
<td>Recalls a minimum of essential terms and factual information</td>
<td>Recalls virtually no essential terms and factual information</td>
<td>No work shown for this section</td>
</tr>
</tbody>
</table>

Recalls virtually all essential terms and factual information:
- 0 Content Questions were asked to the instructor for the duration of this performance assessment

Recalls most essential terms and factual information:
- 1 Content Question was asked to the instructor for the duration of this performance assessment

Recalls a minimum of essential terms and factual information:
- 2 Content Questions were asked to the instructor for the duration of this performance assessment

Recalls virtually no essential terms and factual information:
- 3 or more Content Questions were asked to the instructor for the duration of this performance assessment

No work shown for this section
APPENDIX B: FINAL ASSESSMENT

B.1 Final Assessment Rubric

**FINAL GRADING RUBRIC**

Name _______________________________ Score _____ /20 _____ % Grade _____

Choose one of the following as a way to present the evidence for either the Kirsten K. murder or the murder of Larry J.:

1. Create a concept map showing the chain of events (including evidence from each assessment and motives for each suspect) for the murder
2. Create a timeline of the murder cases, showing pictures and use of evidence along the timeline.
3. Create a forensics board, showing pictures of the suspects and victims, including evidence from each assessment that is relevant to each
4. Create a shoe box model of a recreation of the crime scene from a bird’s-eye view for one of the murders including labeled evidence
5. Write a script for how the court room trial would go for one of the murders (and act it out with classmates)
6. Create a PowerPoint that would be used in a court case as if you are a forensics specialist called in to testify about the murder
7. Another approved project by the instructor

### Overall Project Format (Interview about project by teacher)

<table>
<thead>
<tr>
<th>Application</th>
<th>wgt</th>
<th>Exemplary (10)</th>
<th>At Standard (8)</th>
<th>In Progress (7)</th>
<th>Still Emerging (6)</th>
<th>No Evaluation (0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication Skills</td>
<td>**</td>
<td>Project: follows a typical forensics case format from the above choices and would help in organizing evidence to solve the case</td>
<td>3 of 4</td>
<td>2 of 4</td>
<td>1 of 4</td>
<td>No work shown for this section</td>
</tr>
<tr>
<td>Evidence Presentation</td>
<td></td>
<td>Presentation to Teacher/Class: you will be asked to verbally explain your model upon completing the final project</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evidence Presentation</td>
<td></td>
<td>Originality: your project is unique</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evidence Presentation</td>
<td></td>
<td>Accuracy: the information in the project is correct</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connecting Ideas</td>
<td>1d</td>
<td>** Makes insightful connections between ideas or events that might not be obvious; abstract thinking evident (4 of 4)</td>
<td>Makes general, logical connections between ideas or events; mostly concrete in nature (3 of 4)</td>
<td>Makes superficial connections between ideas; thinking might be confused or incomplete (2 of 4)</td>
<td>Makes incorrect or no connections between ideas (1 of 4)</td>
<td>No work shown for this section</td>
</tr>
<tr>
<td>Connecting Ideas</td>
<td></td>
<td>Evidence from each of the 5 assessments were used in the model or write-up</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connecting Ideas</td>
<td></td>
<td>Evidence is used to form a believable motive for either the murder of Kirsten K. and Larry J.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connecting Ideas</td>
<td></td>
<td>A connection between the suspects, the motive and evidence is shown by the project chosen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connecting Ideas</td>
<td></td>
<td>The performance assessment number and part is listed with each piece of evidence</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
B.2 Student Samples of Final Projects

*Student Example: Forensics Board*

*Student Example: Murder Timeline*
Student Example: Concept Map
APPENDIX C: CLASSROOM NORMS

Classroom Norms

1. Pausing, “Share the Air”
2. Paraphrasing
3. Posing questions
4. Putting ideas on the table
5. Paying attention to self & others
APPENDIX D: DISCUSSION STARTERS

Discussion Sentence Starters

<table>
<thead>
<tr>
<th>Entering the Conversation</th>
<th>Paraphrasing</th>
</tr>
</thead>
<tbody>
<tr>
<td>• An idea I have is….</td>
<td>• You just said that…</td>
</tr>
<tr>
<td>• I noticed that ….</td>
<td>• To paraphrase what you just said…</td>
</tr>
<tr>
<td>• I can’t stop thinking about…</td>
<td>• Let me see if I heard you right. You just said…</td>
</tr>
<tr>
<td>• I’m wondering…</td>
<td>• What I understood was…</td>
</tr>
<tr>
<td>• That reminds me of….</td>
<td>• In other words, you’re saying that…</td>
</tr>
<tr>
<td>• A theory I’m developing is…</td>
<td>• I’m hearing that…</td>
</tr>
<tr>
<td></td>
<td>• It sounds like you think that…</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elaborating and Clarifying</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sentence Starters</strong></td>
</tr>
<tr>
<td>• I think it means…</td>
</tr>
<tr>
<td>• In other words…</td>
</tr>
<tr>
<td>• More specifically it is...</td>
</tr>
<tr>
<td>• It’s important because…</td>
</tr>
<tr>
<td>• It affects readers by…</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Synthesizing/Summarizing Conversation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sentence Starters</strong></td>
</tr>
<tr>
<td>• We can say that…</td>
</tr>
<tr>
<td>• We can agree that…</td>
</tr>
<tr>
<td>• Even though some might think…</td>
</tr>
<tr>
<td>we conclude that…</td>
</tr>
<tr>
<td>• It all boils down to…</td>
</tr>
</tbody>
</table>
## Supporting Ideas with Evidence

<table>
<thead>
<tr>
<th>Sentence Starters</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>For example...</td>
<td>Where does it say that?</td>
</tr>
<tr>
<td>In the text it said that...</td>
<td>What is a real-world example?</td>
</tr>
<tr>
<td>One case that illustrates this is...</td>
<td>What's an example of that idea?</td>
</tr>
<tr>
<td>Remember in the example we did__, it said...</td>
<td>Can you give evidence from the text?</td>
</tr>
<tr>
<td>I can prove this because...</td>
<td></td>
</tr>
<tr>
<td>One example from my life is...</td>
<td></td>
</tr>
</tbody>
</table>

## Building on and Challenging

<table>
<thead>
<tr>
<th>Sentence Starters</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building off what you said...</td>
<td>How can we add to the idea of...?</td>
</tr>
<tr>
<td>Adding onto what__said...</td>
<td>What other ideas or examples relate to this idea?</td>
</tr>
<tr>
<td>I agree with__, and I want to add...</td>
<td>What else could support this idea?</td>
</tr>
<tr>
<td>That idea connects to...</td>
<td>Why or why not?</td>
</tr>
<tr>
<td>I found another example for what__brought up, on/in...</td>
<td>What contradicts this idea?</td>
</tr>
<tr>
<td>I noticed some of the same things that__did, but also thought...</td>
<td>What are other points of view?</td>
</tr>
<tr>
<td>I respectfully disagree with__ because...</td>
<td></td>
</tr>
</tbody>
</table>
E.1 Student Engagement Survey

This survey will be provided before and after the activity. Please answer the questions below in regard to the activities we've done in class this year. Rather than considering the term "activity" as a specific instance, this can be viewed as the general format of class over the course of the year (notes, labs, practice problems, etc.)

Name

Your answer

1. I lost myself in this science activity

1 2 3 4 5

Strongly Agree

Strongly Disagree

2. I was so involved in the science activity that I lost track of time.

1 2 3 4 5

Strongly Agree

Strongly Disagree
3. I blocked out things around me while I was doing this science activity.

   1  2  3  4  5

   Strongly Agree  ○  ○  ○  ○  ○   Strongly Disagree

4. When I was doing this science activity, I lost track of the world around me.

   1  2  3  4  5

   Strongly Agree  ○  ○  ○  ○  ○   Strongly Disagree

5. The time I spent doing this science activity just slipped away.

   1  2  3  4  5

   Strongly Agree  ○  ○  ○  ○  ○   Strongly Disagree

6. I was absorbed in my science activity.

   1  2  3  4  5

   Strongly Agree  ○  ○  ○  ○  ○   Strongly Disagree

7. During the science activity I let myself go.

   1  2  3  4  5

   Strongly Agree  ○  ○  ○  ○  ○   Strongly Disagree
8. I was really drawn into my science activity.

1 2 3 4 5

Strongly Agree ○ ○ ○ ○ ○ Strongly Disagree

9. I felt involved in this science activity.

1 2 3 4 5

Strongly Agree ○ ○ ○ ○ ○ Strongly Disagree

10. This science activity was fun.

1 2 3 4 5

Strongly Agree ○ ○ ○ ○ ○ Strongly Disagree

11. I continued to think about this science activity because I was curious.

1 2 3 4 5

Strongly Agree ○ ○ ○ ○ ○ Strongly Disagree

12. The content of the science activity made me curious.

1 2 3 4 5

Strongly Agree ○ ○ ○ ○ ○ Strongly Disagree
13. I felt interested in this science activity.

1  2  3  4  5
Strongly Agree  ○  ○  ○  ○  ○  Strongly Disagree

14. This science activity was worthwhile

1  2  3  4  5
Strongly Agree  ○  ○  ○  ○  ○  Strongly Disagree

15. I consider this science activity a success.

1  2  3  4  5
Strongly Agree  ○  ○  ○  ○  ○  Strongly Disagree

16. This science activity did not work out the way I had planned.

1  2  3  4  5
Strongly Agree  ○  ○  ○  ○  ○  Strongly Disagree

17. This science activity was rewarding.

1  2  3  4  5
Strongly Agree  ○  ○  ○  ○  ○  Strongly Disagree
18. I would recommend this science activity to my friends and family.

1  2  3  4  5

Strongly Agree 〇 〇 〇 〇 〇  Strongly Disagree

19. I felt frustrated while doing this science activity.

1  2  3  4  5

Strongly Agree 〇 〇 〇 〇 〇  Strongly Disagree

20. This science activity was confusing.

1  2  3  4  5

Strongly Agree 〇 〇 〇 〇 〇  Strongly Disagree

21. I felt annoyed while doing this science activity.

1  2  3  4  5

Strongly Agree 〇 〇 〇 〇 〇  Strongly Disagree

22. I felt discouraged while doing this science activity.

1  2  3  4  5

Strongly Agree 〇 〇 〇 〇 〇  Strongly Disagree
23. This science activity was challenging.

1 2 3 4 5

Strongly Agree ○ ○ ○ ○ ○ Strongly Disagree

24. This science activity was demanding.

1 2 3 4 5

Strongly Agree ○ ○ ○ ○ ○ Strongly Disagree

25. I could not do some of the things I needed to do in this science activity.

1 2 3 4 5

Strongly Agree ○ ○ ○ ○ ○ Strongly Disagree
27. Do you think students in the grade below you should do this activity in chemistry class next year? Why or why not?
I personally wasn’t the most interested in this activity. This may have been that personally with my first group, it seemed like we had a good idea who did the killing to begin with and we were just doing a lot of “unnecessary” experiments to confirm it. Obviously not unnecessary as in the real world it is very necessary to do these steps to prove the situation but I feel the activity just wasn’t really for me. With that said I believe that it is a great group activity and social building activity and should be done with the next group and my opinion is purely just based off the topic of the activity we were doing not group activities in general. In terms of group activities it was a great group building and collaborative experience.

1 response

I think that if possible, it should be made optional. I think this because it was a very stressful activity and I think it is made more stressful when people who don’t want to do the project are forced to do the project. Or maybe allow more time to work on the project. I felt very rushed throughout the activity which made it harder to fully learn everything. I was also very stressed about the grade, because I had trouble understanding exactly what the court case slideshow was supposed to be. So I definitely think that this activity should be given to next years class because it was fun and a different way of learning, but maybe making some adjustments to reduce stress.

1 response

Yes, I believe it was beneficial and fun, but I think that next time it would be better if the teacher creates all the groups without considering friend groups. I actually found it easier to work in a group where I wasn’t friends with anyone because I was less tempted to get distracted or start talking about something else.

1 response
The yes they should, monitor groups better though, more choice in the groups would’ve made me care a lot more, or if I was with people who were the kind of people to actually do the work and get along.

1 response

Yes, I think this was a very beneficial unit. It wrapped up what we had learned earlier in the year and was also just very fun overall.

1 response

Yes. It was fun and really interesting. Very different from units I have previously done, but in a good way.

1 response

Sure, some people may be interested in this type of activity and may not have easy access to it elsewhere.

1 response

Yea because it’s a fun science activity that still makes you learn stuff and apply teamwork and skills
<table>
<thead>
<tr>
<th>Yes. It was nothing like other group work I'd done before, and was more challenging but still doable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 response</td>
</tr>
<tr>
<td>Yes but I hope they could make it a longer unit. I hope they can take more time to do each step</td>
</tr>
<tr>
<td>1 response</td>
</tr>
<tr>
<td>Yes because it was a lot of fun and helped me work with people I wasn't used to working with.</td>
</tr>
<tr>
<td>1 response</td>
</tr>
<tr>
<td>Yes definitely, it is an interesting unit that requires a decent amount of group work.</td>
</tr>
<tr>
<td>1 response</td>
</tr>
<tr>
<td>I believe they should because it helps develop teamwork and leadership skills.</td>
</tr>
</tbody>
</table>
Yes, because it was a nice fun activity to end off the school year.

1 response

yes, it was fun and not that hard and I liked working in a group

1 response

yes because it was generally fun I just didn’t enjoy my group

1 response

yes because it was very engaging and made the class very fun

1 response

yeah it was something different and it was enjoyable
28. Please feel free to share any comments or suggestions about this activity.
The activity was pretty good but I feel like the combination of people that were put together was sub-optimal. If the goal of this activity is to build teamwork skills we should be put with people who we are less familiar with because if you are paired up with friends it's not going to be hard to communicate. I constantly found myself frustrated because some of the people in my group wouldn't focus on the activity and ended up slowing down the progress that I was making. I'm sure you heard me yelling a little bit but that wasn't necessarily because I was mad at people it was to try and get their attention because conventional methods weren't working. I found that increasing my volume and changing my tone helped the group to focus kinda like a deer in the headlights strategy. Next year you should also include strategies to help get the attention of distracted coworkers instead of having to make one up as I did.

1 response

Thank you for allowing our class to do an end of the year activity that was different from the rest of the year. I think that even though it was a bit stressful, it was still a fun way to end the year. The packets for the activity were very well thought out and definitely were interesting while still being challenging.

1 response

My answers to this are regarding the final project not the groups before that, also my answers for the previous segment are in reference to my group rather than the project itself, the project itself wasn't bad but my group was
<table>
<thead>
<tr>
<th>Comment</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is hard to have a group grade because some people weren't as involved or interested in the project.</td>
<td>1 response</td>
</tr>
<tr>
<td>I think it was a fun activity, but I feel it could also be better as an individual activity too.</td>
<td>1 response</td>
</tr>
<tr>
<td>I can't speak for other groups, but ours worked together very well.</td>
<td>1 response</td>
</tr>
<tr>
<td>The first groups should be of 4 people or less</td>
<td>1 response</td>
</tr>
<tr>
<td>You did good a job with making it fun</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX F: STUDENT SELF-REFLECTIONS

F.1 Student Self-Reflection Survey

Forensics Reflection

Name:

Your answer

1) From the list of norms what do you think you're practicing well? Why?

Your answer

2) Which of the norms should you work on more? Why?

Your answer

3) How is your group working together overall? What are some positive and negatives that you've noticed?

Your answer

4) Do you have any recommendations for me?

Your answer
F.2 Student Self-Reflection Responses after Evidence Collection Groups

1) From the list of norms what do you think you're practicing well? Why?

| Putting ideas on the table, I'm used to being a leader |
| All of the norms for collaboration because I can't remember not doing any of those things |
| We are quite effective at posing ideas and processing them. |
| Pausing, we are good at pausing and letting other people talk |
| I did well with putting ideas on the table; I suggested things when they came to me. |
| Posing Questions. We are very good at making sure we are all on the same page. We always ask questions when we are unsure of any steps. |
| The best ones I've practiced have been posing questions, paying attention to others, and putting ideas on the table. As I've been doing all of these during the activities and if I'm confused or have an idea |
| All, we communicated well as a group and were able to all but forth ideas and were able to communicate well. |
| Paying attention to self and others because I believe that I do a good job monitoring myself and helping others be apart of the conversation. |
| Putting Ideas on the table, I feel that I have been contributing towards the group very well and adding ideas as to how to solve problems in a way that benefits the group and helps everyone understand. |
| I believe that I am practicing posing questions well because I am not afraid to speak up when I'm struggling to understand something or need someone to go slower through the packet. |
| Pausing, because everyone else is working really fast and I'm kinda making them all pause. |
| Posing questions because I ask my group to fill me in when I get behind. |
| 5, 2, 4. |
| Paying attention to self and others because whenever someone is behind I always try to be aware of that and catch them up |
| I feel like I propose different ways to solve a problem well by putting ideas on the table. I also think that I try to keep the group together and include everyone in problem solving. |
| Pausing because I pose an idea or make a statement then pause to see if anyone in my group talks more on what I said. |
| I think I am practicing posing questions well, because when I don't understand something I ask which helps me understand better and maybe others understand better as well. |
| Paying attention to self and others, putting ideas on the table. Because when people are talking |
| I am practicing listening and paying attention to others.
2) Which of the norms should you work on more? Why?

pausing, I tend to rush ahead of others

None because I don’t remember falling any of the norms

Clarification?
paraphrasing cause it doesn’t happen

Pausing, I tend to just blurt out when I have an idea.

We should work on Paraphrasing because we tend to make things far more long-winded than they need to be.

Paraphrasing and shortening down what I’m saying a lot more.

None, we worked well on everything as a group.

Putting ideas on the table because sometimes I hope others will answer before me so I don’t have to be wrong.

Pausing, I feel that I sometimes over share and that I need to work on slowing down and letting others speak and ask questions if need be.

I believe that I should work on the paraphrasing norm because I will sometimes ask questions and then go quiet upon receiving the answer.

Posing questions, because I’m struggling to get my questions out there.

Paraphrasing because I didn’t do it that much

Putting ideas on table

Putting ideas on the table

Paraphrase

Posing questions

Posing questions. Because I should ask how people got that answer/mindset.

Paying attention to others so I don’t miss things.

3, 1.

paraphrasing because I usually can understand the wording of the article

I guess the pausing and paraphrasing I could do better. Sometimes if somebody doesn’t understand something I find it hard to reword it or teach it to them how I did it.

Paraphrasing just to ensure I understand and to help others understand what someone is probably trying to say.

Putting ideas on the table because most of the time I am not very sure of myself and my answers so I hold back what I have and wait for someone else to speak up first.

I would say paraphrasing. I don’t really know why, but I just feel that I need to improve in this area.

Putting idea on the table.
3) How is your group working together overall? What are some positive and negatives that you've noticed?

<table>
<thead>
<tr>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our group works very well together because we all know each other very well and are comfortable speaking with each other.</td>
<td>We need to work on addressing conflicts more effectively.</td>
</tr>
<tr>
<td>Our group is good at functioning effectively and we have a good time as well.</td>
<td>We need to improve our collaboration skills.</td>
</tr>
<tr>
<td>good</td>
<td></td>
</tr>
<tr>
<td>We are working together very well, we all participate and we are progressing through the lab very quickly.</td>
<td></td>
</tr>
<tr>
<td>We are working good together, and we are all very comfortable with each other as a group.</td>
<td></td>
</tr>
<tr>
<td>Great we all pitch our ideas, participate, and agree</td>
<td></td>
</tr>
<tr>
<td>Good, work well together, N/A</td>
<td></td>
</tr>
<tr>
<td>Pretty good, getting the work done so that’s a plus...</td>
<td></td>
</tr>
<tr>
<td>I feel that we work well together. Even though we may have differences once in a while on how we would like to go about solving problems.</td>
<td></td>
</tr>
<tr>
<td>Our group is working very well together and are good at communicating with each other while working. One positive that I noticed is that no one is shamed for wrong answers. One negative that I’ve noticed is that we have trouble all being in the same spot in the packet.</td>
<td></td>
</tr>
<tr>
<td>Working OK together. Some positives is that everyone has added something. A negative would be that we are struggling to communicate with each other due to personal differences.</td>
<td></td>
</tr>
<tr>
<td>there wasn’t many positives to be honest unless you wanna count the very small group formed in the already small group. the very small group worked better since it was like partner work as opposed to group work. since the group was particularly excluding me and a classmate had a better time and understood the material better when we worked together than we did as a whole group. a fellow classmate in the group asked several questions and was ignored several times and it was frustrating to be two pairs instead of the on small group like we were supposed to.</td>
<td></td>
</tr>
<tr>
<td>all positive no negative, congratulations</td>
<td></td>
</tr>
<tr>
<td>there are some people who are really smart and just cruise through while others are struggling to actually understand what’s even happening</td>
<td></td>
</tr>
<tr>
<td>Meh, each person has a very different pace of work so it doesn’t flow great</td>
<td></td>
</tr>
<tr>
<td>We are working well, I think some people are taking control too much but other than that good. also i havent been here so idk</td>
<td></td>
</tr>
<tr>
<td>I’ve noticed its easier to have more minds sometimes.</td>
<td></td>
</tr>
<tr>
<td>We work together well. We go at a pace where everyone gets the information and are good at explaining things to others.</td>
<td></td>
</tr>
<tr>
<td>we mesh very well with each other and are all willing to slow down to help one person, however we are easily sidetracked.</td>
<td></td>
</tr>
<tr>
<td>We are good at working together and catching each other up.</td>
<td></td>
</tr>
<tr>
<td>For the most part our group works together fine but there is a person in the group that kind of isn’t working with the rest of the group and is kind of going on their own and not explaining their methods.</td>
<td></td>
</tr>
<tr>
<td>We do put a lot of ideas on the table and pose a lot of questions but I think people should slow down and pause more to let people catch up and also paraphrase everyone’s thinking so we’re on the same page.</td>
<td></td>
</tr>
<tr>
<td>We are good, some positives are that we get along well, and we take what each other say and we build upon that in our own answers. Some negatives are that when we first started it was kind of a split group and sometimes we just start doing work on our own and don’t share.</td>
<td></td>
</tr>
</tbody>
</table>

I feel that my group is working well overall. We talk about stuff that we are stuck on. But one thing that I would like us to do it be more like a group. Sometimes people skip ahead, and some people don’t really like to be included.

I feel like we are not working all that well together. The group seems very split. Half of the group is working alone and the other half is attempting to collaborate. When questions are asked, they are often ignored. Half of the group seems very focused on finishing the task rather than understanding and working together and understanding what needs to be understood. Its frustrating when some people are trying to understand and others are shutting them out. Its hard to understand and keep up when everyone is at a different place and no collaboration from one half is happening.
F.3 Student Self-Reflection Responses after Synthesis Groups

1) From the list of norms what do you think you're practicing well in your final group? Why?

ALL
Contribing Ideas, Listening, all of it.
Putting ideas on the table
Putting ideas on the table
Putting ideas on the table
Putting ideas on the table
Putting ideas on the table because we all actively participated and worked well
Paying attention to self and others and putting ideas on the table
posing questions because we are asking questions
Putting ideas on the table, and paying attention to self and others.
Posing Questions because I feel like we all have separate ideas on what happened but all questioning the ideas put out to see which one makes the most sense.
Our group is really good at putting ideas on the table and reworking other people's ideas to make more sense. We have been presenting a ton of theories, some of them seem logical and others need work from the group to make more sense.
posing questions
Posing questions. We work well together and are asking many questions as to what each of us thinks really happened.
posing questions cause as we're trying to figure out what happened we're asking questions and thinking
yes.
Putting ideas on the table

I think that I am doing better with posing questions to clarify whats going on.
All of the norms were performing well because we're interested in the subject
Putting ideas on the table. Because because I'm putting ideas on the table.
Posing questions, it is much easier to have a closer discussion with smaller groups.
Putting ideas on the table. We all are contributing evenly to the discussion.
Putting Ideas on the Table because everyone is participating very well
putting ideas on the table
We are proficient at putting forward ideas and incorporating people's ideas into our timeline.
All of them. We all ask questions when we have them, put ideas on the table, pay attention and listen to each other. And we all paraphrase and pause when needed to get other people a chance to participate.

NUnumber 4 and 1
Pausing
2) Which of the norms should you work on more in your final group? Why?

<table>
<thead>
<tr>
<th>none</th>
</tr>
</thead>
<tbody>
<tr>
<td>theing?</td>
</tr>
<tr>
<td>Paraphrasing</td>
</tr>
<tr>
<td>paraphrasing</td>
</tr>
<tr>
<td>paraphrasing because sometimes the topic uses big words we all don't get</td>
</tr>
<tr>
<td>Pausing</td>
</tr>
<tr>
<td>paying attention to self and others. Sometimes people cut off others ideas</td>
</tr>
<tr>
<td>Paraphrasing</td>
</tr>
<tr>
<td>Paying attention to self and others because sometimes some people don't seem included.</td>
</tr>
<tr>
<td>I don't think there really even is anything that our group needs to work on. Our group is pretty good at making sure we are all on the same page, asking questions, rewording other's work, and making sure that everyone is involved.</td>
</tr>
<tr>
<td>pausing, cause we all talk at the same time</td>
</tr>
<tr>
<td>pausing. I feel like I still over share a lot.</td>
</tr>
<tr>
<td>pausing cause we were all talking at the same time trying to figure out what happened</td>
</tr>
<tr>
<td>most, you know why</td>
</tr>
<tr>
<td>Pausing</td>
</tr>
<tr>
<td>Putting idea on the table. I am not as good at doing this when I am with people that I am not close with. I was close with my first group so I felt more comfortable. Its harder for me to put idea on the table, but i am working on it.</td>
</tr>
<tr>
<td>none because we were good at them all</td>
</tr>
<tr>
<td>pausing. Because I feel i should talk slower and make sure people know what i'm saying.</td>
</tr>
<tr>
<td>Pausing, rather than blurtng things out I specifically tend to just blurt out ideas.</td>
</tr>
<tr>
<td>Paraphrasing. We tend to draw out our explanations more Ethan necessary.</td>
</tr>
<tr>
<td>Posing questions we don't ask a lot of questions, we just make a bunch of theories which isn't bad, but not exactly what a we are supposed to do</td>
</tr>
<tr>
<td>paraphrasing</td>
</tr>
<tr>
<td>Simplicity to our ideas could make our workload quicker.</td>
</tr>
<tr>
<td>Couldn't probably work more on paraphrasing</td>
</tr>
<tr>
<td>2, 3, and 5</td>
</tr>
<tr>
<td>Paraphrasing</td>
</tr>
</tbody>
</table>
3) How is your new group working together overall? What are some positive and negatives that you’ve noticed?

- All positive effective communication and works well together
- it’s ok not any positives or negatives
- work well together, get nothing done

Were all working really well together. There’s less people so I think it’s a lot less clutter if that makes sense.

Good. We all have a sort of different thought process which is both good and bad.

Good, we get along. I don’t have anything negative really

Some people add more and put more of their information on the table but some people aren’t really participating.

I think we work well together bc we all get along and listen to each other’s ideas and find ways to include all ideas.

We work very well together. We all bring something to the group

Everyone in the group is working pretty well together. We are respectful of each other’s ideas.

It’s okay. Positive is there’s more idea ass negative is that there’s more ideas.

I feel that it works good overall. I like the small groups.

Really good we all click well and have fun. I think we just need to work on all being a part.

Super good. We are working very well together, but maybe we are getting a little distracted from the real collected evidence at times.

good

I think over all well. We all share and communicate. But I feel that some work alone more than others too.

good we work well together

50/50, little work by them.

We are working well. One positive thing we do is easily explain and understand each others’ ideas. One negative thing is that we all say ideas at once and don’t pause to collect our thoughts often.

Positive is that we have good group discussions.

Negative is that not everyone cares about the project so it sometimes makes me nervous because I want a 4 but not everyone is concerned with it, but most people are.

The group was working well.

We are working together well. Some positive things are that we all are on the same page and are getting stuff done. There are no negatives.

We are all working together very well. Everyone has equal involvement.

We are working together very well. We all contribute evenly and that’s good.

Really good, communication is better and we are all participating.

We are working fine just a bit talkative.

My new group is a good group as we all did some work in our groups, which given the groups, is about 50-50 for getting someone who did the work. I’ve already stated the positives and negatives.

Our new group is working well, we all put ideas on the table and put others ideas into consideration.

More communication is happening, but not all of it is on topic conversation.

We all pay attention.
## APPENDIX G: FIELD NOTE COLLECTION TRACKING SHEET

<table>
<thead>
<tr>
<th>Group #:</th>
<th>Collaboration</th>
<th>Critical Thinking</th>
<th>Other</th>
<th>Quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>People</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Perspectives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Evidence /</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Synthesis /</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Build /</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Share Ideas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Generate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arguments /</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reason</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meta /</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Priority</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Apply to Solve</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Problems</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## APPENDIX H: HABITS OF WORK RUBRIC

### HABITS OF WORK RUBRIC

<table>
<thead>
<tr>
<th></th>
<th>Exceeds the Standard</th>
<th>Meets the Standard</th>
<th>Partially Meets the Standard</th>
<th>Does Not Meet the Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Assignment Completion</strong></td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Consistently completes work by the due date.</td>
<td></td>
<td>Typically completes work by the due date.</td>
<td>Sometimes submits work after the due date or does not submit.</td>
<td>Rarely submits work by the due date or does not submit.</td>
</tr>
<tr>
<td><strong>Responsibility</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consistently arrives to class on time and prepared.</td>
<td></td>
<td>Typically arrives to class on time and prepared.</td>
<td>Sometimes arrives to class on time and prepared.</td>
<td>Rarely arrives to class on time and prepared.</td>
</tr>
<tr>
<td>Consistently follows class routines.</td>
<td></td>
<td>Typically follows class routines.</td>
<td>Sometimes follows class routines.</td>
<td>Rarely follows class routines.</td>
</tr>
<tr>
<td>Consistently advocates for self as needed.</td>
<td></td>
<td>Typically advocates for self as needed.</td>
<td>Sometimes advocates for self as needed.</td>
<td>Rarely advocates for self.</td>
</tr>
<tr>
<td><strong>Time Management</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consistently engages in class activities.</td>
<td></td>
<td>Typically engages in class activities.</td>
<td>Sometimes engages in class activities.</td>
<td>Rarely engages in class activities.</td>
</tr>
<tr>
<td>Consistently uses entire class time efficiently and effectively.</td>
<td></td>
<td>Typically uses class time efficiently and effectively.</td>
<td>Sometimes uses class time efficiently and effectively.</td>
<td>Rarely uses class time efficiently and effectively.</td>
</tr>
<tr>
<td><strong>Respect</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consistently works well with others.</td>
<td></td>
<td>Typically works well with others.</td>
<td>Sometimes works well with others.</td>
<td>Rarely works well with others.</td>
</tr>
<tr>
<td>Consistently listens actively and speaks respectfully.</td>
<td></td>
<td>Typically listens and speaks respectfully.</td>
<td>Sometimes listens and speaks respectfully.</td>
<td>Rarely listens and speaks respectfully.</td>
</tr>
<tr>
<td>Consistently works through distractions.</td>
<td></td>
<td>Typically works through distractions.</td>
<td>Sometimes distracted and/or creates distractions for others.</td>
<td>Often distracted and creates distractions for others.</td>
</tr>
</tbody>
</table>
BIOGRAPHY OF THE AUTHOR

Brianna DeGone was born in Lewiston, Maine on May 21, 1995. She was raised in Turner, Maine and graduated from Leavitt Area High School in 2014. She attended the University of Maine and graduated in 2018 with a bachelor’s degree in bioengineering as the class salutatorian and the outstanding student in the college of engineering. In her undergraduate career, Brianna was an athlete on the UMaine track and field team, an Ernest F. Hollings Scholar through the National Oceanic and Atmospheric Administration, and interned with IDEXX Laboratory in Westbrook, Maine. After graduation, she began working as a process engineer at IDEXX and after two years decided to change her profession and become a secondary science educator. Brianna returned to the University of Maine and entered the graduate program in teaching through the Maine Center for Research in STEM Education. After receiving her degree, Brianna will continue teaching high school chemistry at Leavitt Area High School in Turner, Maine. Brianna is a candidate for the Master of Science degree in Teaching from the University of Maine in December 2021.