LABORATORY DEVELOPMENT FOR RELEVANT STUDENT LEARNING

by

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Dedicated to my family for their continued support and love.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This work utilizes a model of relevance in science education by Stuckey, Hofstein, Mamlok-Naaman, and Eiliks (2013) to develop laboratory activities. In an Agriculture and Health and Human Science major chemistry course from a large Midwestern university, three different laboratory activities have been developed to include real-world applications of chemical concepts important to the student's possible interests and future careers. These include an intermolecular forces lab utilizing surfactants and collard greens, a potato lab utilizing enzyme kinetics, and a titrations lab utilizing hard water. Although these laboratory activities are still under development, their procedures and content are presented here.

CHAPTER 1. INTRODUCTION

Laboratory classes have been scrutinized frequently on a number of different aspects. Laboratory activities designed to lead students from procedure to correct results or "cookbook laboratories" are presented as a poor method to teach critical thinking (Hake, 1997, Hofstein and Lunetta, 2004, Isozaki, 2017). These laboratory activities fail to help students learn how to reason inductively when procedures are not discussed by students and teachers (Isozaki, 2017). Similarly, Abrahams and Millar (2008) found in post lesson interviews where cookbook laboratory activities took place, the majority of students could only recall the procedure and not the core concepts behind the activity.

Laboratory activities have also been seen as a misuse of time and money when compared with the benefits in student learning (Kirschner and Meester, 1988). In their 1988 review of problems facing laboratories, the authors found there was little justification for the use of laboratories and stated that the price of running laboratory classes was arguably too high for little improvement to students' conceptual knowledge.

Hofstein and Lunetta (1982) concluded in their review of research on laboratory learning that engaging in laboratory "failed to show simplistic relationships between experiences in the laboratory and student learning." Their review found no measurable difference in student learning when comparing laboratory activities to teacher demonstrations, computer simulations, and filmed experiments. The authors encouraged more narrow research designed to measure the benefits of laboratory experiences.

Twenty years later, Hofstein and Lunetta (2004) re-visited the same topic to review changes in laboratory research. The authors were disappointed to find a lack of research demonstrating the clear benefits of laboratory activities. However, in both reviews, the authors claimed that creating meaningful and productive activities in a laboratory setting was possible. Hofstein and Lunetta (1982) also discussed the possible benefits of laboratory activities on students' attitudes in chemistry, their problem-solving skills, and students' communication and soft skills. In addition, the authors' 2004 publication stated well designed inquiry activities can help students learn how to design investigations and learn concepts. The next few sections include attempts to build off of Hofstein and Lunetta's call for additional research and work to create laboratory activities focused on these improvements of student learning.

1.1 Successful Laboratory Activities

1.1.1 Bridging the Gap:

Research into laboratory activities has attempted to fill the gap presented by Hofstein and Lunetta (1982, 2004). To study 14-16-year-old students' view points on science education, a student-led survey was overseen by Murray and Reiss (2005). The results showed laboratory experiments were a top method for student learning. In the survey two prompts were presented; one to discern which learning methods were most useful and one to discern which learning methods were most enjoyable. Of the eleven different methods presented, laboratory experiences placed third in both categories. Under the category of most useful, discussions and debate ranked first and student note taking was ranked second. Field trips and videos were ranked first and second as most enjoyable methods to learning science. These student responses show, at minimum, an importance of laboratory work to students.

While students enjoy learning from laboratory activities, they may not be getting the full benefit of the experience. Abraham (2011) found the learning goals of instructors for laboratory activities do not match the method by which they are implemented. Two-hundred and three general chemistry teachers were presented five categories for learning in chemistry; facts, concepts, processes, skills (laboratory and mathematical), and attitudes. Of the learning categories, the majority of general chemistry professors stated the learning of concepts was the most important. However, when asked if laboratory activities belonged before or after the corresponding lecture content, 80% of general chemistry professors stated it belonged after lecture content. When the activity proceeds the lecture, it becomes more verifying in nature as opposed to inquiry (Abraham, 2011). Verification activities tend to prompt rote learning instead of meaningful learning (Ausubel, 1962, Eubanks, 2015).

Another criticism of laboratory practice is the lack of clearly defined goals for learning (Hofstein and Mamlok-Naaman, 2007, Bruck and Towns, 2013). Learning goals or objectives are an important starting point when developing and implementing learning activities. Clear goals and objectives facilitate the instructor's development of the lab activity and the measurement of the student's understanding (Abrahams and Millar, 2008). Bruck, Towns, and Bretz (2010) explored instructor goals for laboratory activities by interviewing 22 professors of varying levels of chemistry courses. The most common goals stated by professors include:

1. Research Experience
2. Group Work/Conversation Skills
3. Data Collection, Analysis, and Error Analysis
4. Connecting Laboratory Activities and Lecture
5. Learning Lab-Specific Transferrable Skills
6. Learning Non-Lab-Specific Transferrable Skills
7. Laboratory Writing

The goals emphasized by general chemistry instructors were group work and connecting laboratory activities to the lecture material. This matches the findings of Abrahams (2011). Instructor goals for laboratory activities are necessary, but in order for students to accomplish those goals, they must be presented to them. Hart, Mulhall, Berry, Loughran, and Gunstone (2000) theorized that instructor goals need to be shared with students, including the activity's continuity within the unit material in order to increase the probability that students will meaningfully engage. In other words, not only the primary learning objective, but also why the laboratory activity was presented is necessary information for students (Hart et al., 2000, Hodson, 2001).

While instructors' goals are important, the goals of students are also critical for developing successful laboratory activities (Hofstein and Mamlok-Naaman, 2007). Santos-Díaz, Hensiek, Owings, and Towns (2019) surveyed undergraduate chemistry students' goals in laboratory. The survey contained a list of thirteen goals coded from an open-ended survey question. The list includes:

1. To earn an A or B
2. To prepare for the career I want to pursue
3. To develop my scientific writing skills
4. To make connections between lab and the real world
5. To understand how a chemistry research lab works
6. To learn lab techniques
7. To be efficient in lab
8. To prepare for future science courses
9. To connect concepts learned in lectures with laboratories
10. To work as a team
11. To learn how to design and carry out experiments

12. To carry out experiments safely
13. To apply lab techniques

The survey prompted students to label the thirteen student goals as either "most important," "important," or "least important" to laboratory activities. Given before and after the semester, the top three most influential goals pre-semester were acquiring an A or B, preparing for future careers, and preparing for future chemistry courses. Post-semester, "being efficient in lab," had a sharp increase in the number of "most important" and "important" responses. Given this increase, Santos-Dias et al. (2019) matches the findings of Dekorver and Towns (2015). When comparing student and instructor goals in laboratory, Dekorver and Towns (2015) found, from a small sample of students, the main goals of students were to complete the laboratory activity swiftly and correctly. This mismatch of student and instructor goals can hinder the learning of students in laboratory activities (Hodson, 2001, Hofstein and Lunetta, 2004).

1.1.2 Meaningful Learning:

Meaningful learning has been stated frequently so far without any definition. Ausubel's theory of subsumption and retention (1962) states two types of learning, rote and meaningful, can occur. The difference between these learning types lies with the process of adding new concepts to existing knowledge hierarchies. Rote learning adds new information as its own hierarchy without any connection to previous knowledge. On the other end of the spectrum, meaningful learning adds new information to existing hierarchies (Ausubel, 1962, Ausubel, 1962, Novak, 1993). While both can be retained, meaningful learning is more resistant to forgetfulness (Ausubel, 1962).

Ausubel (1962) stated three conditions that need to be met for meaningful learning to occur: past knowledge hierarchies need to be present to be added to, new concepts need to be clear and stable, and new concepts must be discriminable from the learning activity. Over time, simplified requirements for meaningful learning were given (Driscoll, 2000):

1. Students must have appropriate background knowledge for new content;
2. The content must be presented in a meaningful way; and,
3. The student must actively incorporate the new information into the already existing information;

Novak's theory of human constructivism builds upon Ausubel's theory by the addition of specifically human domains of learning: cognitive, affective, and psychomotor (Novak, 1993, Bretz, 2001). Bretz (2001) explains that meaningful learning will only occur when educational experiences touch on all three domains. Laboratory experiences have unique opportunities to utilize all three domains in a singular context. Table 1 defines these domains based on Bretz (2001).

Table 1: Bretz's (2001) table for information on the three learning domains of Novak's Human Constructivism.

Learning Domain	**Types of Knowledge**	**Examples**
Cognitive	concepts, reasoning skills	equilibrium, enthalpy, periodic trends
Affective	attitudes, motivations	risk assessment, careers in chemistry
Psychomotor	dexterity, precision	molecular modeling, titrations

Given the large impact Ausubel's theory of meaningful learning had on Novak's theory of human constructivism, the three requirements for meaningful learning still apply to human constructivism. Dekorver and Towns (2015) categorized students' and educators' goals in the three learning domains stated earlier. In addition to the discrepancy of goals between students and educators, the domains these goals fell under were also mismatched. Faculty focused on goals within the psychomotor and cognitive domains while the students' focus was more affective in nature. As stated before, mismatching goals by student and teachers impedes learning (Hodson, 2001 & Hofstein and Lunetta, 2004). Therefore, attending to students' goals of preparing for future careers and chemistry courses (Santos-Dias et al., 2019) may be able to help students' learning from laboratory activities.

1.2 Learning Chemistry in a Shape

Ubiquitous in science education is Johnstone's Triangle (Johnstone, 1982, Talanquer, 2011, and Taber, 2013). The three points of this triangle coincide with the macroscopic, submicroscopic (microscopic/molecular), and symbolic domains. The triangle can be seen in Figure 1 taken from Mahafy (2004).

Utilizing this geometric representation, an educator can help guide their students to operate at the center of Johnstone's triangle. Novice chemists have a difficult time switching between all three levels freely, and Johnstone (1991) even argues that most students who are not pursuing chemistry as a career could survive using only macroscopic views. However, if a student is wanting to pursue further chemistry education, they must be able to freely move between domains.

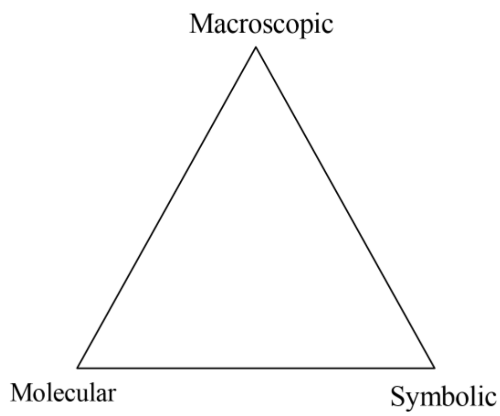


Figure 1: Johnstone’s triangle of chemistry learning.

Personalizing learning has led to further development of Johnstone’s Triangle to include more dimensions. Mahaffy (2004) introduced the human element in his tetrahedron of chemical learning. Figure 2 shows the geometric interpretation of Mahaffy’s adaptation in relation to the original triangle. The human aspect of the tetrahedron takes into account a variety of different variables including social, economic, political, environmental, philosophical, and historical aspects. Mahaffy suggests that to support the human element in the classroom, faculty should utilize projects, case studies, and active learning.

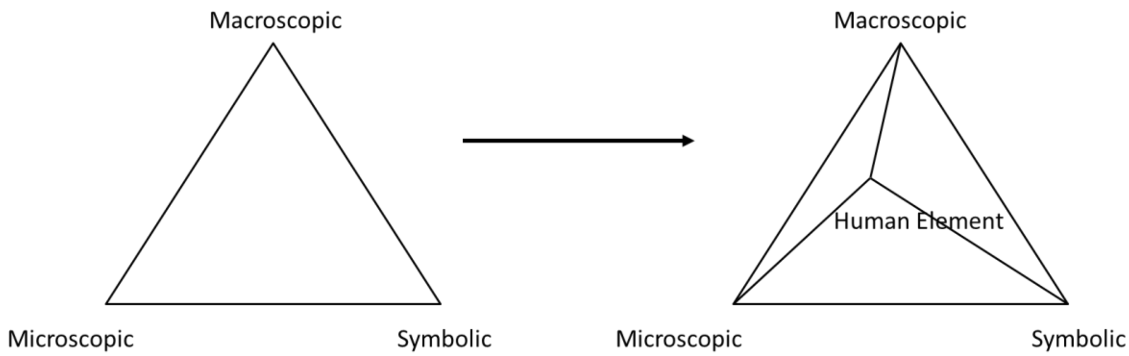


Figure 2: This figure shows Mahaffy’s (2004) geometric adaptation of Johnstone’s triangle to incorporate the human aspect of chemistry.

Building off Mahaffy’s tetrahedron, Sjöström and Talanquer (2014) added to the human element of the tetrahedron and split the pyramid into four different levels of operation. These levels include the very base of the tetrahedron which covers pure chemistry, the second level which covers applied chemistry, the third covering socio-chemistry, and the fourth level containing critical reflexive chemistry. Applied chemistry focuses on the introduction of relevant real-world and everyday instances of chemistry to the classroom and is the aspect of chemical learning focused in future chapters.

1.2.1 Relevance

Relevance has had many definitions in science education (Feng and Tuan, 2005, Hofstein and Kesner, 2006, Rannikmäe, Teppo, and Holbrook, 2010). Stuckey, Hofstein, Mamlok-Naaman, and Eiliks (2013) accumulated these definitions into a model of relevancy in science education which includes the individual, societal, and vocational. The individual dimension focuses on student interests and motivations; the societal dimension focuses on students’ idea of themselves in society and their duty as a citizen; and the vocational dimension focuses on the expectations of a students’ chosen career. Depending on what the educator’s goal is for a lesson, this model can help determine on which dimension the educator focuses. Educators must find the common interest or goal of their students and match their unit to the appropriate dimension. The model is shown in Figure 3.

Relevance has been defined as student interests. Increasing this motivation has led to ideas such as gamification of learning and game-based learning (Hensiek et al., 2016, Towns, Harwood, Robertshaw, Daubenfeld and Zenker, 2014). The individual dimension of the relevancy model by Stuckey et al. (2013) includes this intrinsic motivation of students. However, as Rannikmäe, Teppo, and Holbrook (2010) described, relevancy includes more than just student interest and motivation. They define relevance as something valuable, meaningful, or useful to students. So, this definition includes things that may not be entertaining but information that is valuable to students.

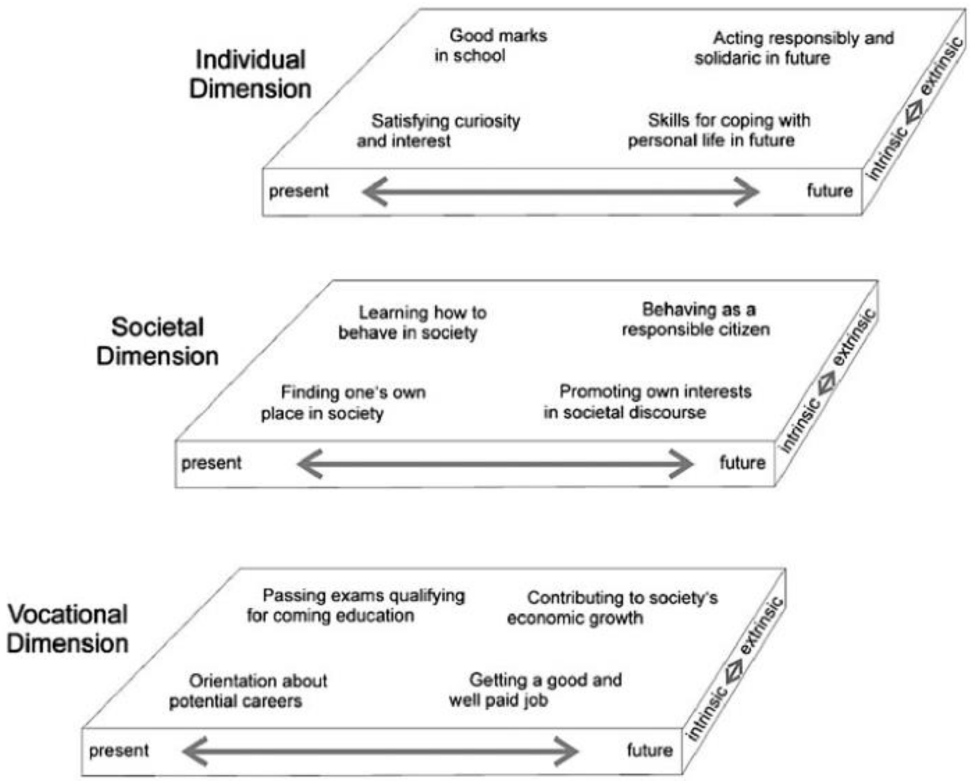


Figure 3: Model of relevancy in science education developed by Stuckey et al., (2013).

Stuckey et al. (2013) elaborated on the definition of relevant learning to include necessary and useful material in terms of students' future careers. The vocational dimension takes advice from Rannikae et al. (2010) to include aspects of science students might find valuable to future careers.

Work by Hofstein and Kesner (2006) adds another dimension to the definition of relevant science education. The authors implemented a number of case studies on industrial chemistry to a high school chemistry course in Israel. These case studies helped introduce students to the different chemistry careers in industry and their connections to different disciplines. The author's contribution to the definition of relevant learning includes the social aspect of science with the inclusion of environmental issues to the case studies.

Relevancy in science education meshes well with Human constructivism. Pienta and Wink (2005) wrote a chapter on relevancy in learning theories and stated the importance of instructor participation in discussion of the "relevant" scenario, as well as the material having continuity with past and future class content. This enables the presented material to have appropriate background for students, as well as a meaningful presentation, which falls in line with the requirements of Ausubel's theory of meaningful learning (Ausubel, 1962).

However, the application of relevant material does not automatically lead to success. A problem that can rise from introducing relevancy to an activity is essentializing students. Pienta and Wink (2005) elaborated on this phenomenon stating when students are not actively participating in meaningful learning, they are closed off to the connections of content and real-world applications. As a result, meaningful learning will not occur. As an educator, the applied level of chemical learning assumes students are going to find material important and be open to incorporating new knowledge into existing hierarchies. When professors assume students will have this "essence" of learning, those who do not will not learn meaningfully. They have been "essentialized." An example of a kitchen physics activity presented to a class of girls would essentialize the group and break down the group into a general idea of interests, and those students who did not connect with the activity will not participate in meaningful learning (Barad, 2000 in Wink, 2005). To facilitate meaningful learning, instructors should guide the students through activities by being actively present in discussion and helping students connect the new relevant material to past and future concepts (Ausubel, 1960 & Wink, 2005).

Stuckey et al. (2013) also present another problem with relevancy-based instructions in terms of assessment. Though the content of the classroom is relevant and engaging, students are often still assessed on chemical concepts outside the relevant context of the classroom. This requires the assessments of a relevance-based course to also test within the same context of relevance.

Some successful applications of relevant student experiences can be found in Wink's chapter (2005). Goll and Woods (1999) wrote about a chemical activity using the movie "Apollo 13" which was released in 1995. The movie shows the explosion of an oxygen tank and the mission's change to a survival venture. The authors incorporated the movie into a lesson on observation and hypothesis, asking for reasonings and ideas about why the tank exploded, as well as a section on chemical reactions within the tank itself. The authors' goal for the activity was the showing of applied chemistry and the creativity involved in creating and changing hypotheses. Sherwood, Kinzer, Bransford, and Franks (1987) provided a similar situation in their activity on "Indiana Jones and the Raiders of the Lost Ark". The clip showed was Indiana Jones utilizing a bag of sand to replace a golden idol on a booby-trapped pedestal. From this clip, a lesson on density was given using the same motivations and macro-context as Goll and Woods (1999). Wink (2005) describes these activities as a great example of instructors advising and guiding students through seeing a macroscopic idea from a movie and making it a relevant learning environment.

Feng and Tuan (2005) presented a successful use of Keller's Attention, Relevance, Confidence, and Satisfaction (ARCS) model (Keller, 1999) to motivate 11th graders in learning acids and bases. The unit contained several modules containing frequent real-world applications from things like common flower and vegetable dye indicators to acid rain discussions. The authors compared the motivations towards science of a control group of students who were taught in a conventional lecture and an experimental class taught using the ARCS developed unit. A questionnaire prompting student motivation was given to both groups before and after the unit and the results showed an increase in student motivation in the ARCS-based classroom.

Though the definition of relevant science education has changed, the goal to benefit students' learning has not. The model for relevant science teaching developed by Stuckey et al. (2013) meshes well with the applied domain of chemical learning and was used to guide the work presented in the following chapters.

1.3 Overview of Work

The following chapters present the work I have done to develop relevant laboratory learning activities for agriculture and health and human science majors (enrolled in CHM 11100 and 11200) at a large Midwestern university. I will present the background literature and origins of the laboratory, the overview of the activity, the changes implemented, any relevant data taken over the course of development, and the implications and future work for each new laboratory activity. Chapter 2 is an adapted lab dealing with intermolecular forces on leaf surfaces. Chapter 3 is an adapted enzyme kinetics lab utilizing the browning of potatoes. Finally, Chapter 4 is in the process of altering a hard water activity dealing with herbicide usage.

CHAPTER 2. INTERMOLECULAR FORCES LEAF LAB

2.1 Introduction

Research on student understanding of intermolecular forces has revealed some struggles students face learning this content (Schmidt, Kaufmann, and Treagust, 2009, Cooper, Williams, and Underwood, 2015, & Bruck, 2016). Schmidt et al. (2009) found four common ideas high school and general chemistry students use to determine if molecules can interact through hydrogen bonding. The ideas are not correct on their own. Only when a combination of them is used are students completely correct. These ideas are:

1. The molecule contains oxygen and hydrogen
2. Hydrogen is bonded to a certain atom (N, O, F)
3. Positive ends of dipoles orient to the negative ends of another
4. Hydrogen of one molecule interacts with a highly electronegative atom (N,O, F) of another molecule

The students were asked to discern if a molecule could form hydrogen bonds with another molecule of the same structure and were free to justify their answers. In the seven questions presented to students, only one question received over 35% correct answers.

Cooper et al. (2015) found students have an incomplete understanding of how molecules interact through IMFs. The authors compared students' written and illustrated answers from an intermolecular forces assessment. Students were often ambiguous in writing where IMFs were taking place. Noyes and Cooper (2019) argued that scaffolding of assessment questions helped students to more fully answer mechanistic question on IMFs. However, illustrated answers showed the majority of students believed that intermolecular forces are present within the same molecule (Cooper et al., 2015). The authors advocated for IMFs to be taught in connection to topics that are needed to understand them. This includes molecular structure, shape, and polarity.

Bruck (2016) found concept building through hands-on activities can increase student understanding of IMFs for present and future courses. The author focused on introducing intermolecular forces using a three-part hands-on activity. Part one drew a hands-on analogy between IMFs and the interaction of magnets of different strength. Students could then physically compare the strength of different "IMFs." In part two, students were asked to color electron density maps. This visually represents the electron cloud of the molecule and helps support student understanding of IMFs. Finally, in part three, students measure the boiling points of three unknown solutions. The students were then asked to rank each solution by the strength of their IMFs. Bruck (2016) stated that this part of the lab was specifically done to show a macroscopic impact of IMFs. A small group of students were broken into an experimental group who participated in the activity and a control group who did not. A comparison of their written responses to an open-ended question on intermolecular forces showed the experimental group significantly outperformed the control.

This chapter presents an altered version of a laboratory activity originally created by Chiu et al. (2016) to help students explore and investigate IMFs. Using the model of relevancy developed by Stuckey et al. (2013), this laboratory activity was developed to utilize the real-world application of surfactants with herbicides to teach IMFs. By focusing on surfactants in the application of agriculture, we access the vocational domain of the relevancy model. Our belief is that the context of this activity can help students meaningfully engage with the topic of IMFs.

2.2 Lab Activity Overview

Our modification was designed as an introduction to a real-world application of IMFs using surfactants. Surfactants are molecules that can decrease the strength of intermolecular forces and lower surface tension. They are used in herbicides to reduce the effect of "beading"(forming of spherical droplets on the leaf surfaces) and spread out the herbicide across the surface of the leaf. In this laboratory activity, students are asked to measure and compare the contact angle of droplets on waxy leaves. Photo Protractor (and ImageJ) is a phone application that allows students to measure the contact angles of droplets. Figure 4 demonstrates how these angles are measured.

The learning objectives for this activity are presented to students as follows:

1. To compare surface properties of plant leaves with/without their epicuticular wax.
2. To compare the wettability of deionized water and surfactants.
3. To use Photo Protractor (originally ImageJ) to measure contact angles from photos.
4. To understand how surfactants change the intermolecular interactions between water and nonpolar surfaces.

As students work through the procedure, they were be able to measure contact angles of water, a surfactant solution of Tween® 20, and a surfactant solution of dish soap. They compared the contact angles of these solutions on leaves with and without the waxy surface. The nature of the different contact angles was then assessed in the students' laboratory report.

The laboratory activity was piloted at the end of the fall 2018 general chemistry course. It was provided as an optional activity for students who wanted to replace a past laboratory score. An estimated 150 students participated in the activity, as well as the post activity survey (see Appendix A). More information about the survey and student responses is presented in the "Implications" section of this chapter.

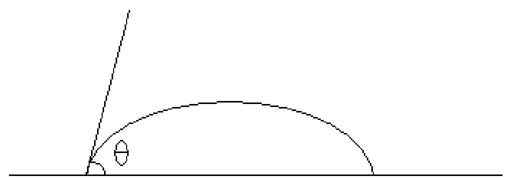


Figure 4: This figure shows an example of how a contact angle is measured.

2.2.1 Our Procedure

This procedure differs from the original activity by Chiu et al. (2016). The changes are discussed in the "Modifications" section of this chapter. The following procedure is condensed by omitting volumes and locations specific to the university's laboratory setting. This information is not necessary to understand the procedure. However, the full laboratory can be seen in Appendix A.

1. Acquire three-leaf sections. There are templates to show what size the cutlets should be, and they should avoid large, veined sections of the leaf to keep the leaf as flat as possible.
2. Put two, eight-inch pieces of double-sided tape parallel to each other on the lab bench. These should be as close to the edge of the table as they can be to ensure good photographs.
3. Place one leaf section down on the taped area as close to the edge as possible. Make sure the cutlet lays generally flat for a good droplet.
4. Take the two-inch brush and lightly brush the right side of the leaf roughly 20 times in each direction. The leaf should look shiny where you brushed.
5. Take your first of the three solutions (DI water, 0.5% Tween® 20 surfactant, 0.5% Dish Soap) and apply one drop to each side of the leaf, making sure to place it on a flat surface near the edge of the lab bench for better photographs.

6. Using your smartphone, get level with the lab bench and take a picture of the droplets.
7. Using the Image J software, measure the contact angle of the droplets on each side of the leaf.
8. Repeat with the other two leaves and solutions.

2.2.2 Modifications

The changes made to the original activity by Chiu et al. (2016) are discussed here. Table 2 lists the modifications and the motivation behind them. As stated in the introduction to Chapter 2, our activity is focused on IMFs and the impact surfactants have on them. This is a good match to the interests of the College of Agriculture students in the non-major's general chemistry course.

Two aspects of the original activity were not utilized. First, we removed a section for students to create a hypothesis for the activity because it did not fall within our learning objectives. Second, we removed a water retention measurement because the cost of creating the apparatus used by Chiu et al. (2016) for the number of students enrolled in general chemistry was too high.

Table 2: Comparison of our modifications and the original laboratory activity.

Original Activity	Modification	Reasoning
Water Retention	Deleted	Cost, excessive, and not practical for the number of students
3x3 cm Leaf Section	Increase to 5x5 cm Leaf Section	Easier brush/no brush separation, increase droplet positions
One Surfactant Used (Tween® 20)	Addition of Dish Soap Surfactant (Tween® 20 and Dish Soap)	Increased relevancy and IMF learning by surfactant comparison
Hypothesis Development Section	Deleted	Emphasis on IMF and surfactant focus

The original activity advised students to use 3x3 cm sections of collard greens for contact angle measurements. In locating the leaf segment and the drop to be imaged, the position of the drop needs to be close enough to the edge of the table for the picture to be taken correctly. The leaf section must lay as flat as possible to obtain good data for the contact angle measurements, and the students must avoid the large veined areas when cutting the leaves. During the process of our work, it was found that a 3x3-centimeter (cm) section was too small for our brushes and for the students to have a clean separation between the brushed and non-brushed areas. To address this issue, we recommended 5x5 cm sections of leaf be used, which allowed for easier brushing without crossing the middle line, as well as more positions to place the drop to ensure quality pictures.

To increase the connection of this activity to the real-world (Sjöström and Talanquer, 2014), a second, more familiar surfactant to everyday life was added, dish soap. The surfactant in the brand of dish soap used is sodium lauryl sulfate. The surfactant utilized in the activity developed by Chiu et al. (2016), Tween® 20, was kept for student comparison. To keep both surfactants comparable, both solutions were made at 0.5% volume. Students could then contrast the contact angles of both surfactants and their chemical formulas to infer what differences in the intermolecular forces are present.

To summarize, the applied aspect of learning IMFs was enhanced by the addition of a familiar surfactant most students have access to in laboratories and at home. This addition includes a real-world connection from the chemistry classroom. The changes applied to our laboratory activity were done to introduce the applied level of chemistry, as well as, ensure students acquired the best data possible.

2.2.3 Additional Information

This section will cover any additional information given to students in the altered version of the laboratory activity. The pre-activity reading starts with the learning goals, so students know what the instructor motivations for the activity are (Hart et al., 2000).

While the learning objectives include understanding intermolecular interactions, IMFs are only briefly covered in the pre-activity reading. The Indiana High School Chemistry Standards include IMFs; therefore, this topic should be past knowledge for students. Students are reminded that intermolecular forces are interactions between molecules (Cooper et al., 2015), as well as, the names of each IMF. One might hope that this will encourage students to recall past hierarchies to use for this learning activity.

After mentioning IMFs, the epicuticular wax is introduced. Students were told the wax functions as a natural barrier to pathogens and protection against dehydration. The reading also states this can be a problem when herbicides and pesticides are sprayed as the wax hinders the interaction of these compounds with the leaf. The wax is described as a mixture of long chained hydrocarbons. The chemical structure of isocaine was provided as an example of a long chain hydrocarbon. The chemical structure was given to students so they could relate the molecule's polarity to its structure. This scaffolding can help students make the connection of IMFs to its real-world applications.

Surfactants are a new topic to most students; therefore, they are briefly mentioned next in the pre-activity reading. Surfactants are described to students as chemical additives to weaken intermolecular forces that are used in agriculture. A simplified illustration of a surfactant was provided to students in the reading, which shows the polar head and nonpolar tail. The structure of Tween® 20 was also provided and aligned with the simple illustration to show where the polar and nonpolar regions are in Tween® 20's chemical structure. This can be seen in Figure 5.

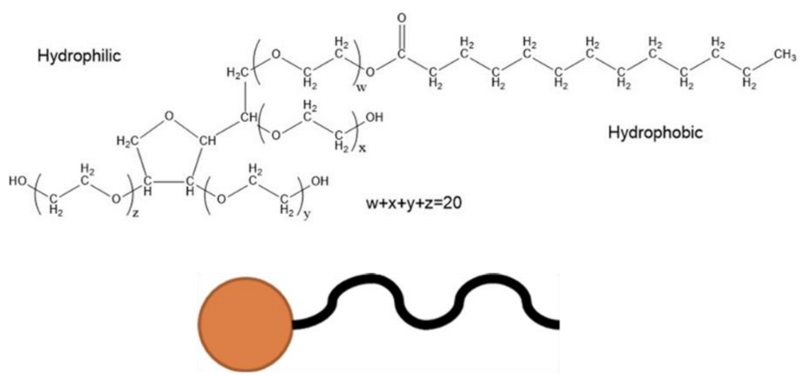


Figure 5: Skeletal structure of Tween® 20 with a simplified drawing of a surfactant shown in the pre-laboratory reading.

Finally, associated with learning objective number two, an introduction to contact angles was required in order to prepare students to collect and interpret this data. Contact angles were described as the way to quantify wettability of a surface. A rubric is provided to the students for a visual reference while performing the activity. This reference shows a range for whether a contact angle has complete, neutral, or incomplete wetting and can be seen in Figure 6. This rubric will help students recognize contact angles as a mathematical representation of everyday situations where liquids form droplets.

Moving from the pre-laboratory activity reading to the post activity questions, students were encouraged to engage in argumentation by asking for data to support their responses and reasoning (Walker, Van Duzor, and Lower, 2018). Learning objectives were also reinforced through the type of questions asked (Hart, 2000) probing the students' ideas about the interactions and surfaces, as well as scaffolding the students reasoning as they moved through the discussion questions.

First, students are asked a series of questions pertaining to the intermolecular forces between the three solutions used in the activity and the leaf surfaces. Next, students are asked to complete a Lewis structure of water and list the types of intermolecular forces present. Then, students are prompted to theorize about the degree of wetting a nonpolar solution would have on a waxy leaf. In the last guiding question, students are presented the skeletal structure of both Tween® 20 and the active surfactant in dish soap, sodium lauryl sulfate. Students are asked to label the hydrophilic and hydrophobic regions of both surfactants.

Finally, the last question probed the ideas students have about the interactions between water and the surfactants. This question prompted students to use their data acquired from the activity to answer: "Studies show that the sodium lauryl sulfate found in dishwashing liquid is a better wetting agent than Tween® 20. Does your data support this claim? Explain using your data." This question requires the understanding of intermolecular forces between water and the hydrophilic heads of surfactants.

To conclude, the pre-activity readings and post-activity questions were included to facilitate a relevant and meaningful activity. The pre-activity reading encouraged students to remember their past knowledge on intermolecular forces. The reading also introduced Sjöström and Talanquer's (2014) applied level of the chemistry tetrahedron through the introduction of surfactants to ensure herbicides are coating waxy leaves. For additional information, the entire activity, including the laboratory report, is presented in Appendix A.

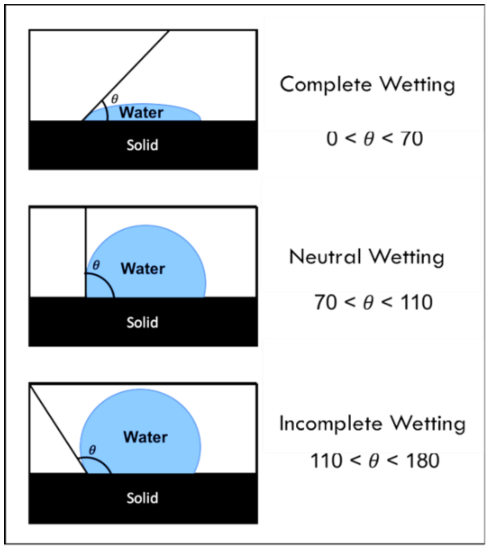


Figure 6: Rubric for determining the degree of a droplet's wetting shown in the pre-laboratory reading.

2.3 Implications

2.3.1 Survey Results

The total number of students who responded to the survey is estimated to be around 150. Students performed the activity in groups of two, and 75 surveys were returned. Since the survey was anonymous, we do not know how many laboratory groups answered as a team or independently. Therefore, we can only estimate the number of students who participated.

The survey includes a table of prompts which probed students' level of agreement. A six-point Likert scale was used ranging from "strongly disagree" to "strongly agree." The survey prompts include:

(P1) This experiment is appropriate for the first week of class, i.e. check-in.

(P2) There was adequate background information given to complete the report.

(P3) Image J was easy to use.

(P4) This experiment gave me a better understanding of surfactants in daily life.

(P5) This experiment relates to the topic of intermolecular forces discussed at the beginning of the semester.

There are a few limitations to the use of this survey. The six-point Likert scale did not allow for any neutral answers to the prompts. This may have resulted in different results for students who neither agreed or disagreed with the prompts. Any additional surveys administered will use a five-point Likert scale.

Also, the purpose of this survey was to acquire input from the students and use the feedback to improve the laboratory activity for future use. No statistical analysis was performed on the results, and therefore, no generalizations can be made about the impact of this activity. Further data will need to be acquired to expand upon the benefits of our activity on student attitudes and learning.

Of all the groups who completed the lab, 75 surveys were returned. Table 3 shows the distribution of student responses from the 75 returned. Less than 27% of the total responses towards all prompts came back negative and the remaining 73% were either “slightly agree” or above.

The prompt that received the most amount of negative feedback (“slightly disagree” or lower) was the installation and use of the ImageJ software. Therefore, an improvement has been made to this activity by using a more accessible software called Photo Protractor. This application is used by the students’ smartphone or tablet to measure angles. To use ImageJ, students had to take a photo of the droplet, email the photo to themselves, save the photo, upload the photo into the ImageJ software, and finally take the contact angle measurement. Photo Protractor cuts out many of those steps since the photo is take on the same device as the angle measurement tool.

Table 3: Distribution of responses to survey prompts on the six-point Likert Scale.

	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree	N
P1	0	2	2	10	31	30	75
P2	1	1	2	10	37	24	75
P3	0	1	10	13	32	19	75
P4	0	3	2	18	28	24	75
P5	0	0	1	7	41	26	75

2.3.2 Future Work

Using common dish soap as a surfactant brought another real-world application into the laboratory activity. Although the response to prompt four was ultimately positive, it received the second highest number of negative responses. This may be attributed to a lack of relatable uses of surfactants. A possible remedy could be introducing more uses for surfactants such as shampoos to ensure dirt and oils get washed away.

Close behind prompt four was prompt one where four groups of students felt they didn't have enough information to answer all the questions on the lab report. Prompt five shows many students understood the intermolecular forces at play, however, some students still felt they did not have enough information. A possible solution is adding more information on how surfactants work into the pre-lab. The introductory reading before coming into lab contains more information on contact angles, molecular structures, and epicuticular waxes than surfactants. This could help improve future responses to prompts number one and four.

I believe I may have essentialized the students with this activity. The pre-activity reading does not discuss the application of surfactants to the health and human science majors. The laboratory may be focused around the application in herbicides to be relevant to the other students. Surfactants do have applications to the medical field. For instance, respiratory distress syndrome is treated by medical surfactants in infants (Sekhon, 2013).

The pre-activity reading needs to be updated to address the concerns of those students who disagreed with the survey prompts. I believe more information can be conveyed to students through the reading. After these edits, I would like to see this activity used to research the impact of relevant contexts to student learning of IMFs.

CHAPTER 3. KINETICS OF BROWNING POTATOES

3.1 Introduction

Students often believe chemical kinetics to be one of the more difficult concepts in chemistry (Marzabal, Delgado, Moreira, Barrientos, & Moreno, 2018). Bain and Towns (2016) reviewed literature on student misconceptions in kinetics and, among the difficulties documented in literature, one specific misconception dealt with catalytic reactions. Students often described catalysts as molecules that increased the rate of reaction with other molecules, however they failed to describe the mechanism by which this change occurs. A catalyst provides an alternative molecular pathway with lower energy requirements for the reaction to proceed. Since enzymes are catalysts, enzymatic reactions provide the same type of chemical reaction to investigate and understand as catalytic reactions. Thus in using enzyme kinetics as a chemical reaction framework, concepts around catalysis and rates could be addressed.

Using concept inventories can help determine what misconceptions students hold. Bretz and Linenberger (2012) created the Enzyme-Substrate Interactions Concept Inventory (ESICI), which evaluates student understanding of enzymatic interactions. While developing the ESICI, the authors interviewed 25 undergraduate and graduate students, and five categories of misconceptions were revealed:

1. Enzyme and Substrate Characteristics
2. The Role of Shape and Charge in Substrate Selectivity
3. How the Enzyme Interacts with the Substrate
4. Competitive vs Noncompetitive Inhibition
5. Conformational Changes

The majority of these categories are too advanced for the general chemistry curriculum. However, categories three and four can be addressed for general chemistry students within our proposed activity. An example of students' misconceptions in category four (competitive vs noncompetitive inhibition) was inhibitors binding to the substrate. In reality, inhibitors bind to the enzyme and change the enzyme's interactions with the substrate.

Utilizing the same ESICI, Linenberger and Bretz (2015) found students (mainly nutrition and exercise science majors) have an alternate conception of where the "active site" is located.

Some students believed the active site was part of the substrate and not the enzyme. In fact, the active site is a location on the enzyme and is where the catalytic reaction takes place.

Our goal for developing this lab activity was for it to be a relevant introduction to enzyme kinetics for non-major, general chemistry students. Enzyme interactions and inhibition are concepts needed to be understood by many of these students in upper-level courses of their majors. An early introduction to these topics can provide students with a foundation to build off of for the future. We recognize and caution that this enzyme kinetics laboratory activity would require alteration to the current lecture material to fully implement in order for the student to understand this type of chemical system. This has not been attempted here, therefore our work on this subject is not ready to pilot.

3.2 Laboratory Overview

Our laboratory activity utilizes the real-world application of fruit or vegetable browning to introduce enzyme interactions to non-major general chemistry students. The activity involves the absorbance measurements of catechol's oxidation by the enzyme polyphenol oxidase. By calculating the rate of reaction of differing concentrations of catechol, Lineweaver-Burke plots can be created. Students determine what type of inhibitor (competitive or noncompetitive) their group was given by comparing Lineweaver-Burk plots of the inhibited and uninhibited data. Our activity was adapted from a laboratory created by Dr. Steve Carman (Carman, n.d.).

3.2.1 Our Procedure

The original activity by Carman (n.d.) was designed for biochemistry students. Therefore, changes needed to be made to use his lab in the general chemistry curriculum. These modifications are expanded on in the "Modifications" section later in this chapter. The following procedure is condensed by omitting volumes and locations specific to the university's laboratory setting. This information is not necessary to understand the procedure.

1. Acquire 12 disposable cuvettes and 3 disposable droppers from your teaching assistant.
2. Acquire the blended potato, Catechol, and your group’s inhibitor solutions (either *trans*-cinnamic acid or lemon juice).
3. In each cuvette, pipet DI water inside.

4. Take six cuvettes and label 1-6. The first cuvette should have 0 drops of Catechol. Using your dropper, put one drop of Catechol in number 2, two drops in number 3, three drops in number 4, four drops in number 5, and finally five drops of Catechol in the sixth cuvette.
5. Set up the spectrometer for a wavelength of 480 nm
6. Get small sections of parafilm and Kimwipes ready for inverting and cleaning cuvettes during the absorbance measurement process.
7. Starting with cuvette number 1, add eight drops of the potato solution to the cuvette and immediately invert, wipe with a Kimwipe, and insert into the spectrometer. Read the absorbance immediately and record that as absorbance at 0 seconds.
8. 30 seconds after inserting the cuvette into the spectrometer, record the absorbance again. This is the absorbance at 30 seconds.
9. Repeat steps 7 and 8 with the next five cuvettes.
10. Repeat steps 1- 10 but add five drops of your group's inhibitor during Step 3.

Data Analysis

1. Import your data to Excel in the same fashion as the report table.
2. Make a column for "velocity of reaction" to find the speed of each cuvette's reaction for the non-inhibited reaction. Each cuvette (1-6) should have a velocity corresponding to it.
3. Next to the velocity column, create another column for the concentration of catechol in each cuvette.
4. Create two more columns. One for a calculation of the inverse of the reaction velocity and one for the calculation of the inverse of the catechol concentration.
5. To calculate these values, go to the first cell in the new column and type "=1/A1" where A1 is just an arbitrary cell number. Use the cell number that corresponds to the first cuvette's reaction velocity.
6. To obtain the rest of the inverse velocities, hover your mouse on the bottom right corner of the cell. Drag your mouse down 5 more cells to apply the calculation to the remaining velocities. (An alternative is using your calculator and imputing the data).

7. Repeat with the concentration of catechol values. The first cuvette with no catechol cannot be calculated as it is a value divided by zero. (Do not include this point in the graph.)
8. With these newly calculated values, create a scatter plot of 1/V versus 1/M.
9. Find the trendline of the graph and display its equation on the graph.

3.2.2 Modifications

Modifications to Dr. Carman's original activity (Carman, n.d.) were done to make the content appropriate for undergraduate chemistry students. All alterations are listed in Table 4 including the motivations behind them.

Table 4: Summary of changes done to the original activity by Carman (n.d.).

Original Activity	Modification	Reasoning
Phenylthiourea (competitive inhibitor)	Replaced with *trans*-cinnamic acid	Safety of student use
Tyrosine (noncompetitive inhibitor)	Replaced with lemon juice (citric acid)	Ease of preparation for prep lab
4 sets of data collected	Decreased to 2 sets of data	More reasonable to complete in 3 hours

Initially, the activity included two different inhibitors: phenylthiourea and tyrosine. The material safety and data sheet (MSDS) for phenylthiourea states the chemical is toxic if ingested and a skin irritant. This competitive inhibitor was removed from use and *trans*-cinnamic acid was used in its place.

Tyrosine was replaced by lemon juice (citric acid) for two reasons. Firstly, when working through the original procedure, we found it difficult to dissolve and to prepare a stock solution. Relieving this burden from the preparatory lab faculty led us to find a replacement. The noncompetitive inhibitor found to replace tyrosine was lemon juice (Ali, El-Gizawy, El-Bassiouny, & Saleh, 2014). While we did not try any other non-competitive inhibitors, lemon juice suited our goals for this lab activity by adding another real-world context to the activity. Many students have seen or even used lemon juice to keep apples from browning. Figure 7 shows the Lineweaver-Burk plot of our data to confirm the inhibition activity of each replacement molecule.

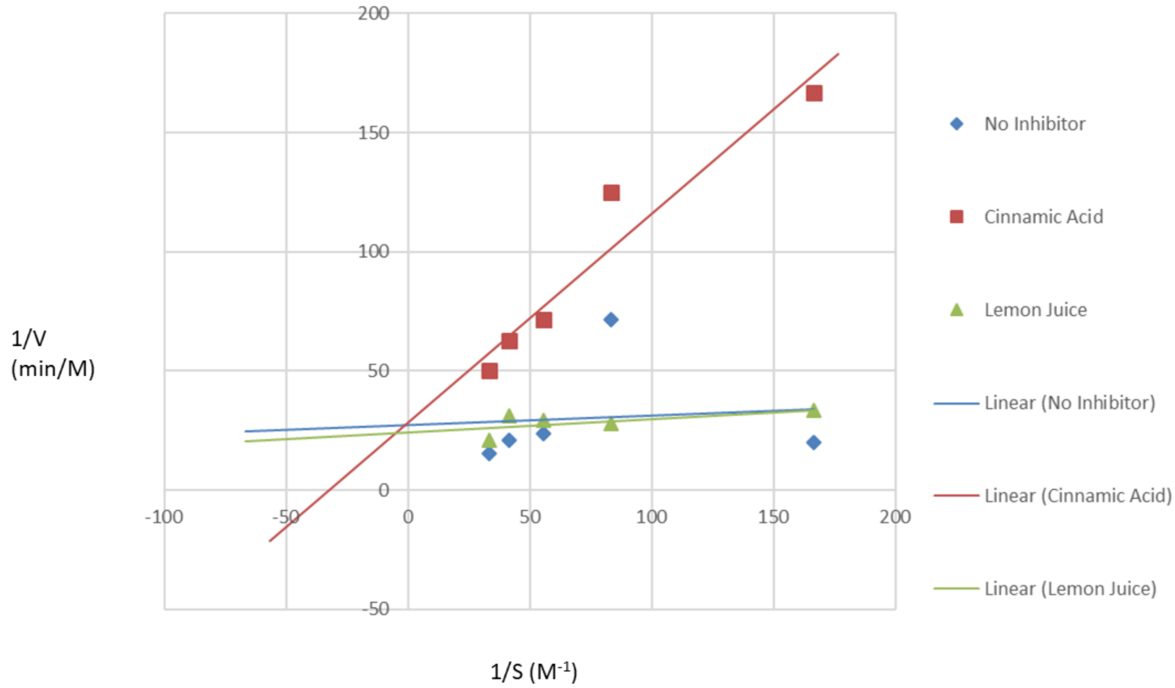


Figure 7: Data from my own experiments for Lineweaver-Burk plots of both inhibited and uninhibited experiments.

The original laboratory activity included four different sets of data to be collected. This included six absorbance readings for the uninhibited reaction and each of the three separate inhibited reactions (originally phenylthiourea, *trans*-cinnamic acid, and tyrosine). For general chemistry students, this is a lot of time sensitive data to collect in one three-hour class period. Therefore, in our activity, students are tasked to complete two sets of six absorbance readings including one uninhibited reaction and one inhibited. Students are then asked to compare their Lineweaver-Burk plots with a group that used a different inhibitor from them. By comparing the two plots, students can determine whether their group's inhibitor was competitive or noncompetitive.

3.2.3 Additional Information

While this activity is not ready to be implemented, the information presented in this section is information believed to be important for students to complete our activity and understand the basics of enzyme-substrate interactions. When the activity is piloted, data from the students can be used to further modify the procedures, analysis, and discussion of the lab's results.

First, enzymes are explained as catalysts. A common two-step enzymatic reaction is given to students to show the use for a catalyst. This equation is then used to visually demonstrate the effects of inhibitors. This equation is labeled as "A" (substrate), "B" (enzyme), and "C" and "D" (reaction products). The reaction is shown as: $A + B \rightarrow AB \rightarrow B + C + D$. This reaction is not described as the only way enzymes react. However, in order to make the reaction as simple as possible visually, the separation of the substrate into two products is an easy way to show if a reaction is proceeding. Figure 8 shows the illustration of the equation above. This visual is also used to show the effect of inhibitors in Figure 9 and Figure 10.

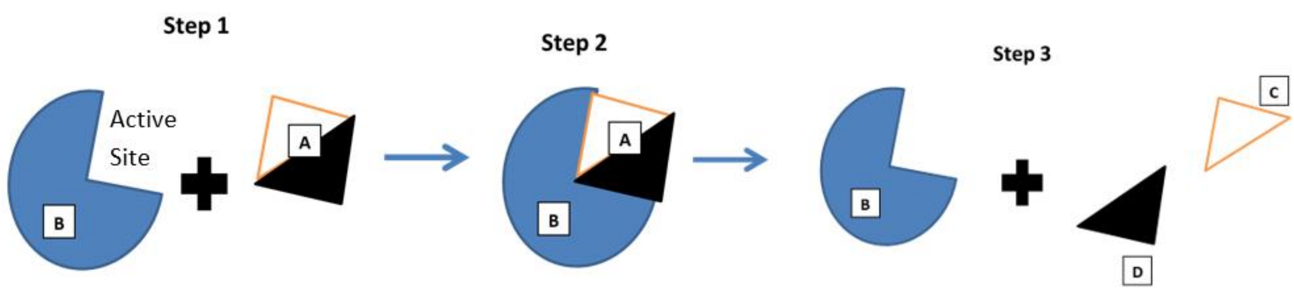


Figure 8: An example of an enzymatic separation of a substrate.

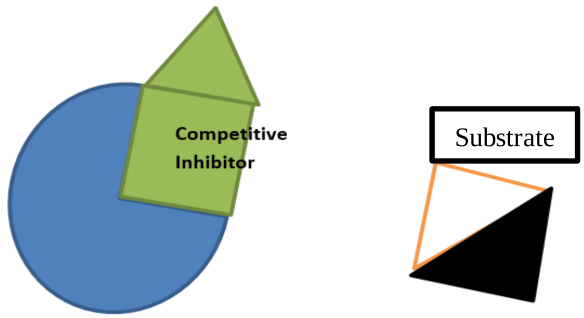


Figure 9: Illustration of competitive inhibition at work in introduction.

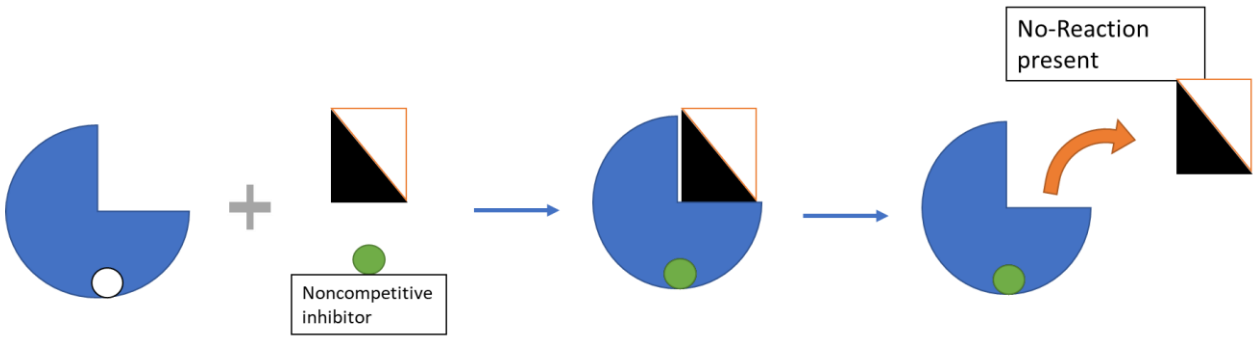


Figure 10 The picture reference of a noncompetitive inhibitor in the introduction.

Given enzymes are catalysts, students are then told that their kinetics are handled differently. To elaborate, a narrative analogy (CITE) of a computer lab is given to students. Students are asked to think about enzyme reactions like a busy computer lab full of people wanting to print their final papers (substrate). Unfortunately, there are only a limited number of computers (enzymes) in the room. This analogy was adapted from Hrycyna (2013).

The analogy can help students by having a macroscopic reference to understand the effects of inhibitors on enzyme reactions. Competitive inhibitors are described as people who just want to use the computer to watch YouTube videos. The people who want to print their paper (the substrate) cannot use the computer while someone is watching videos. Noncompetitive inhibitors are described as the printer technicians. The technicians are working on the printer and, while they are working, people cannot use the computer to print. However, people can still use the computer to do other things except for print documents.

This analogy is used to describe two important constants in enzyme kinetics as well. Max reaction rate (V_{max}) is self-evident in that it shows the fastest a reaction can possibly go. The higher the V_{max}, the faster the reaction can go. The Michaelis constant shows substrate binding affinity (K_m). Binding affinity shows how easily a substrate and enzyme can bind together. The lower the number for K_m, the better an enzyme and substrate can bind together.

The computer lab analogy can help give macroscopic references for the effects of inhibitors on these constants. Competitive inhibitors decrease the binding affinity (increase K_m), but Vmax is unaffected. In the analogy, competitive inhibitors are people who want to use the computers to watch YouTube videos. If someone who doesn't want to print anything is using the computer, the person who wants to print their final paper cannot access that computer (lowers ability for the substrate to bind). However, if someone who is using the computer to print, no one can interfere to watch a video (V_{max} is unaffected).

For noncompetitive inhibitors, the printer technicians impede the ability to print anything from the computer. Even if someone is in the process of printing, the document cannot be made (decreasing V_{max}). However, any person can still use the computer at any time (K_m is unaffected.)

Accompanying the metaphor, a symbolic representation of how to find these constants through graphing is given to the students. Two graphs used to find V_{max} and K_m are provided to students. One graph has axis of "reaction rate" versus "substrate concentration" and can be seen in Figure 11. The other graph (Figure 12) is a Lineweaver-Burk plot and has axis of "the inverse reaction rate" versus "the inverse substrate concentration. Both graphs visually show how to find the constants and could help students analyze their data more effectively.

This information would be given as a pre-activity reading and would reinforce what would be taught in lecture. Since the activity has not been piloted, more work needs to be done to decide what is taught in lecture and what should be emphasized in the laboratory activity.

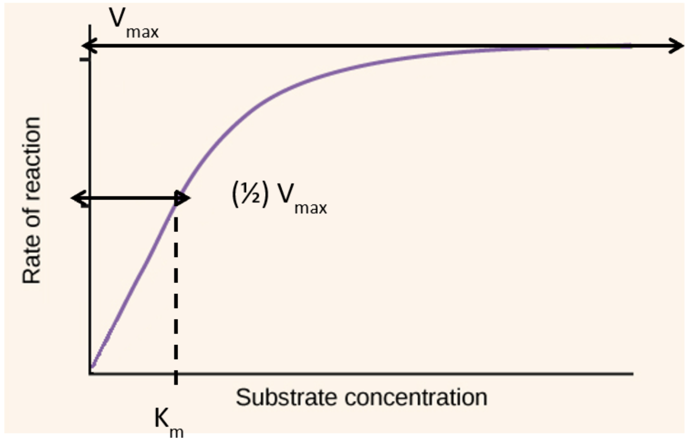


Figure 11: Example for students of a standard Reaction Rate versus Substrate Concentration to find V_{max} and K_m.

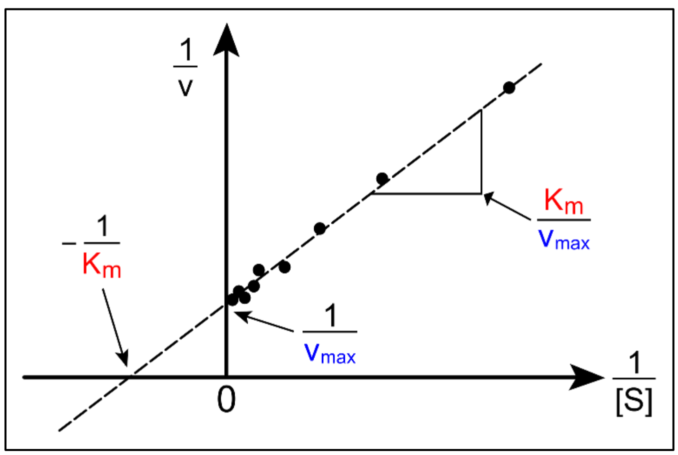


Figure 12: Example for students of a Lineweaver-Burk Plot to find V_{max} and K_m.

3.3 Implications

3.3.1 Limitations

The biggest limitation of this activity is the content. Implementing this laboratory activity would require the addition of more content to an already busy curriculum. Deciding what content should be included in the lecture material will require lengthy discussion with general chemistry instructors as well as the professors of future courses in agriculture and health and human sciences.

While this would be difficult to arrange, it is my belief that this content could benefit students in their future courses and careers.

Secondly, this laboratory is very technical in nature for general chemistry students. When I performed this laboratory activity myself, the most difficult part was keeping the data collection consistent. Each cuvette mixes for thirty seconds and, immediately after this mixing time, an absorbance reading is taken. If students are concerned with getting the laboratory activity done quickly, mistakes can easily be made.

3.3.2 Future Work

The future of this project lies within finalization of procedures and curriculum, as carrying out a pilot study. Preparation includes discussions of at what point in the curriculum to introduce this topic, how in depth the content needs to be, and finally, what assessments, other than the laboratory, should be included. Once the preparations are complete, a pilot study would be needed for the laboratory activity. Then one might envision implementing the modified lecture and laboratory curriculum and obtaining feedback.

CHAPTER 4. HARD WATER AND HERBICIDES

4.1 Introduction

As stated in the introduction, the majority of students who are enrolled in CHM 11100 are agriculture and health and human science majors. The activity presented here involves the topic of chelating metal ions. This chemical concept touches upon both groups of majors and perhaps even their future careers. In agriculture, ethylenediaminetetraacetic acid (EDTA) is used to preserve produce. In health and human sciences, chelation therapy is used to treat metal toxicity (Payne, 2008). In our activity, chelation is used to determine the calcium concentration of tap water.

Hard water is a persistent problem in the Midwestern portion of the United States. Sengupta (2013) stated hard water contains a high concentration of magnesium and calcium. Deposits from hard water often create clogged pipes and stains when magnesium or calcium salts precipitate. Additionally, Sengupta (2013) presented some health effects possibly caused by hard water. This includes a laxative effect from increased magnesium intake, an increased ratio of colon cancer patients to a decrease in hard water, and a protective effect against cerebrovascular disease.

Our hope is to introduce students to another real-world agricultural problem of hard water involving the chelation of herbicides. The herbicide we want to utilize in our activity is 2,4-dichlorophenoxyacetic acid (2,4-D) and, the chemical structure is shown in Figure 13. It is a broad leaf herbicide that requires an empirically known mixing order to work properly in areas of hard water. It is known by those using this herbicide in their profession that a 100-gallon tank needs to have water (usually from a garden hose) added first, then 17 pounds of ammonium sulfate ($(NH_4)_2SO_4$), and finally 2,4-D can be mixed last. If the ammonium sulfate is mixed in after the herbicide, the spray is not as effective at killing weeds.

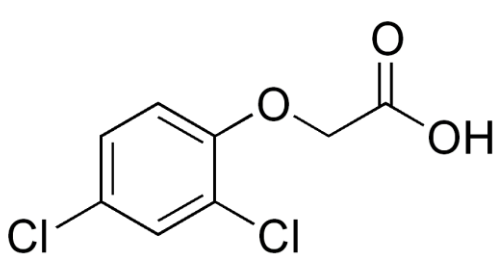


Figure 13: Chemical structure of 2,4-dichlorophenoxyacetic acid.

It has not been experimentally established why the mixing order is so important to the herbicide's effectiveness. However, the empirical nature of the mixing order has been established by those working at Purdue’s turfgrass farm and by those working in the lawn care industry. In this section, we test the theory that when ammonium sulfate is added to the 100-gallon tank last, it allows for 2,4-D to chelate to the calcium in hard water forming a complex. The theorized complex has two molecules of 2,4-D chelated to one ion of calcium and can be seen in Figure 14. This complex is thought to be too large to enter leaf cells and would therefore be ineffective.

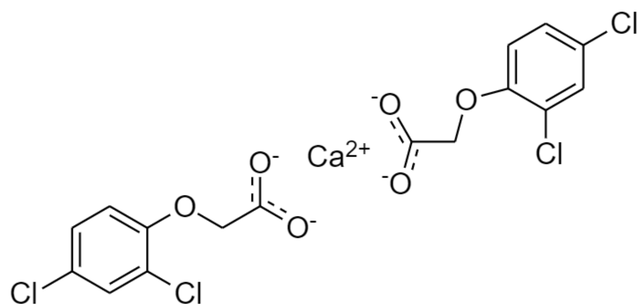


Figure 14: Possible complex formed by hard water and 2,4-D making the herbicide ineffective and the main interaction studied in this section.

When the ammonium sulfate is added before the herbicide, we theorize that a complex is made between the ammonium and 2,4-D. This would only be a single chelated 2,4-D molecule to an ammonium ion and can be seen in Figure 15. This chapter discusses the work done to investigate why this mixing order matters and what complexes may be formed. Once found, it could possibly be added as a real-world problem to a laboratory activity on chelation and hard water.

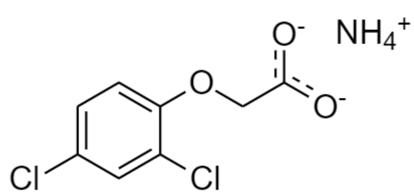


Figure 15: Possible structure for the benefit of $(NH_4)_2SO_4$ addition to herbicide mixing order.

4.2 First Steps

To determine if herbicides interact with metal ions, Thelen, Jackson, ad Penner (1995) utilized nuclear magnetic resonance (NMR). The authors stated their NMR shift when calcium was added to the glyphosate solution showed was an interaction between the glyphosate and calcium ions. Though we believe their data may have been interpreted to confirm more than possible, NMR was our first step in determining if 2,4-D chelates to calcium. NMR readings for 2,4-D, a mixture of 2,4-D and calcium, and a mixture of ammonium sulfate and 2,4-D were taken to determine if any interaction could be measured.

For these NMR measurements, we wanted to keep the concentration of these solutions as close as possible to those used in the lawn care profession. The first solution we made was the calcium or "hard water" solution. According to the Water Quality Association, very hard water contains 180 parts per million (ppm) of calcium. However, to ensure an interaction could be witnessed through NMR, a concentration of 400 ppm calcium was used. The calculation of what concentration in molarity was needed for the NMR measurements is shown below.

$$400\ ppm\ Ca^{2+}$$

$$\left(\frac{400\ mg}{1\ L}\right)\left(\frac{378.5\ L}{1\ Tankard}\right)\left(\frac{1\ g}{1000\ mg}\right) = 151.4\ g\ Ca^{2+}$$

$$\frac{151.4\ g\ Ca^{2+}}{39.963\ {}^{g}/_{mol}\ Ca^{2+}} = 3.789\ moles\ Ca^{2+}$$

$$\frac{3.789\ moles\ Ca^{2+}}{378.5\ L} = 0.0100\ MCa^{2+}$$

Seventeen pounds of ammonium sulfate is added to the worker's tanks when mixing the 2,4-D solution. The molarity calculation for ammonium sulfate is shown below. The concentration used for NMR readings was 0.1541 M.

$$17\ lbs(NH_4)_2SO_4 = 7.71\ kg$$

$$\frac{7.71 \times 10^3 g(NH_4)_2SO_4}{132.14\ {}^{g}/_{mol}\,(NH_4)_2SO_4} = 58.35\ moles(NH_4)_2SO_4$$

$$\frac{58.35\ moles(NH_4)_2SO_4}{378.5\ L} = .1541\ M(NH_4)_2SO_4$$

There is a large difference between the concentration of ammonium sulfate and calcium inside the worker's tanks. In theory, this should result in the formation of solid calcium sulfate ($CaSO_4$). However, workers reported no solid residues inside their tanks, as well as no clogged hoses or sprayers.

Lastly, the concentration of 2,4-D needed to be calculated. We used an 11.84% solution of 2,4-D (from Ace Hardware) and followed the mixing instructions shown on the bottle. The calculation is shown below.

$$1\ gallon\ 2{,}4 - D\ solution: 15\ gallons\ water$$
$$1\ gallon\ 2{,}4 - D\ solution\ has\ 11.84\%\ 2{,}4 - D$$
$$.1184\ gallons\ 2{,}4 - D\ per\ 16\ gallons\ total$$

$$\left(\frac{.1184\ gallons\ 2{,}4 - D}{1}\right)\left(\frac{3785.41\ mL}{1\ gallon}\right) = 448.2\ mL\ 2{,}4 - D$$

$$\left(\frac{16\ total\ gallons}{1}\right)\left(\frac{3.78541\ L}{1\ gallon}\right) = 60.57\ L\ total$$

$$448.2\ mL\ 2{,}4 - D\ * \left(\frac{1.42\ g\ 2{,}4 - D}{1\ mL}\right)\left(\frac{1\ mole}{220.04\ g\ 2{,}4 - D}\right) = 2.89\ moles\ 2{,}4 - D$$

$$\frac{2.89\ moles\ 2{,}4 - D}{60.57\ L\ total\ solution} = 0.0475\ M\ \ 2{,}4 - D$$

These concentrations were utilized to find the volumes necessary for a 10 mL solution similar to the tankards to be made in deuterated water (D_2O). Three different solutions were made for three NMR tests which contained the following:

1. D_2O + 2,4-D (0.0477 M)
2. D_2O + 2,4-D (0.0477 M) + $(NH_4)_2SO_4$ (.1577 M)
3. D_2O + 2,4-D (0.0477 M) + Ca^{2+}(.0100 M)

We first wanted to have a standard NMR reading for 2,4-D as a comparison to those containing ammonium sulfate and calcium. Figures 18 – 21 show these NMR readings respectively and their comparisons to each other.

In all three NMR solutions, there appears to be no interaction between 2,4-D and $(NH_4)_2SO_4$ nor 2,4-D and Ca^{2+}. While this does not mean these molecules are not interacting, however, it does show that NMR is not the method of analysis needed to determine if 2,4-D chelates to calcium or not.

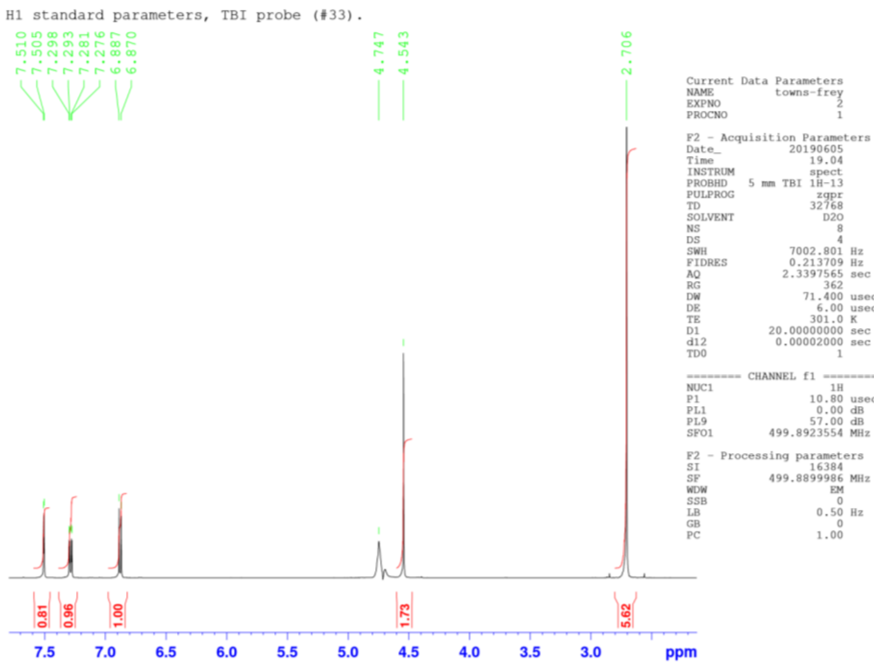


Figure 16: H-NMR for solution 1 containing D_2O and 2,4-D (0.0477 M).

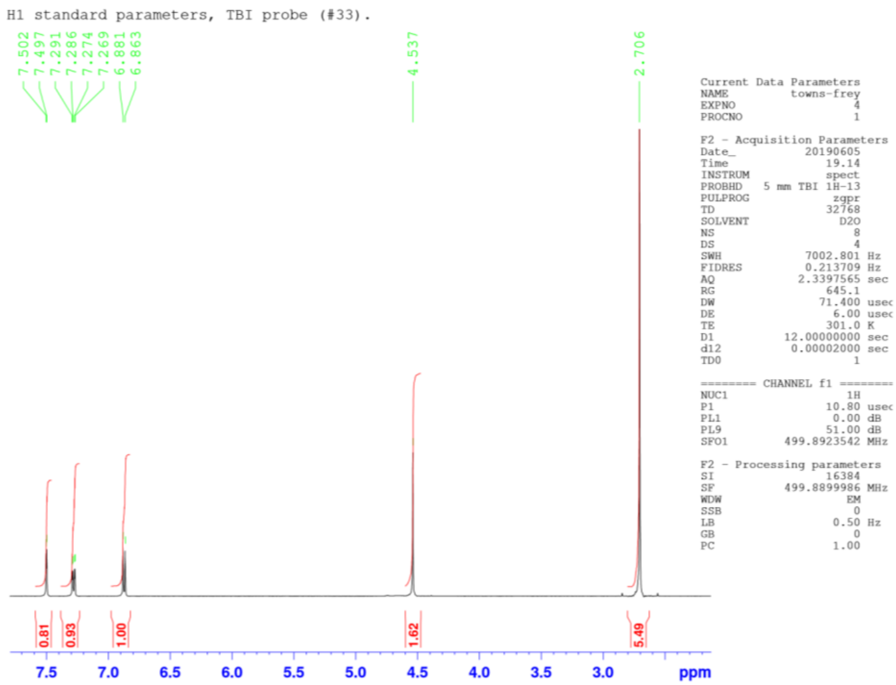


Figure 17: H-NMR for solution 2 containing D_2O and 2,4-D (0.0477 M) and $(NH_4)_2SO_4$ (.1577 M).

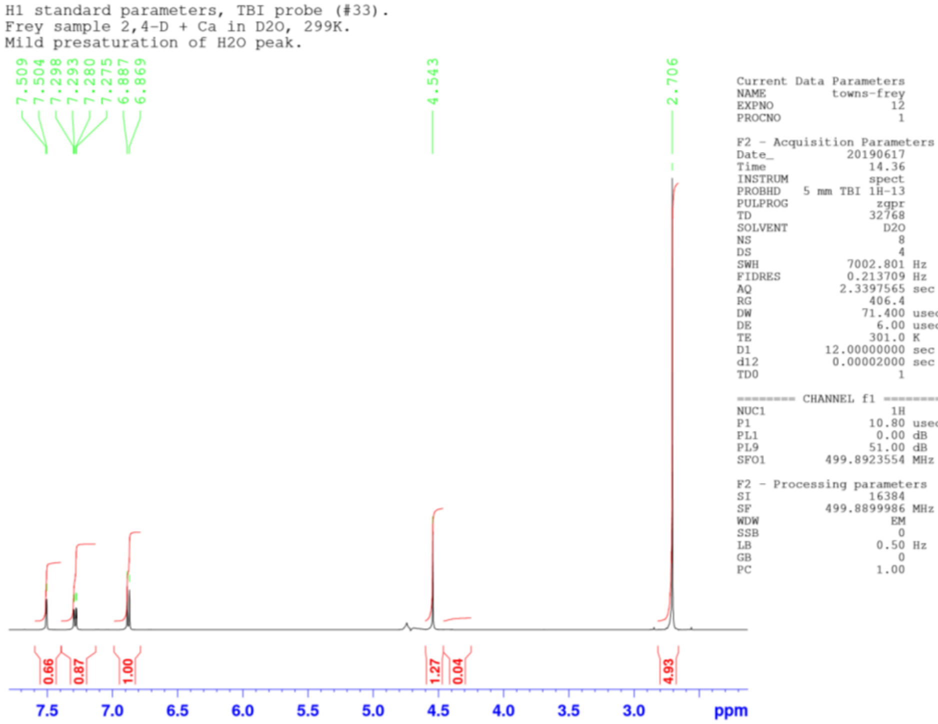


Figure 18: H-NMR for solution 3 containing D_2O and 2,4-D (0.0477 M) and Ca^{2+}.

4.3 Second Step

Since NMR resulted in no noticeable interactions, we decided to try a different method of analysis involving titration. The original laboratory activity titrates an EDTA solution into another solution with an unknown concentration of calcium. EDTA chelates to calcium and the indicator, eriochrome black t (EBT), turns from red to a dark blue when all the calcium is bound. We attempted to replace EDTA with 2,4-D and perform the same procedure. The EBT would then change color if 2,4-D chelates to calcium.

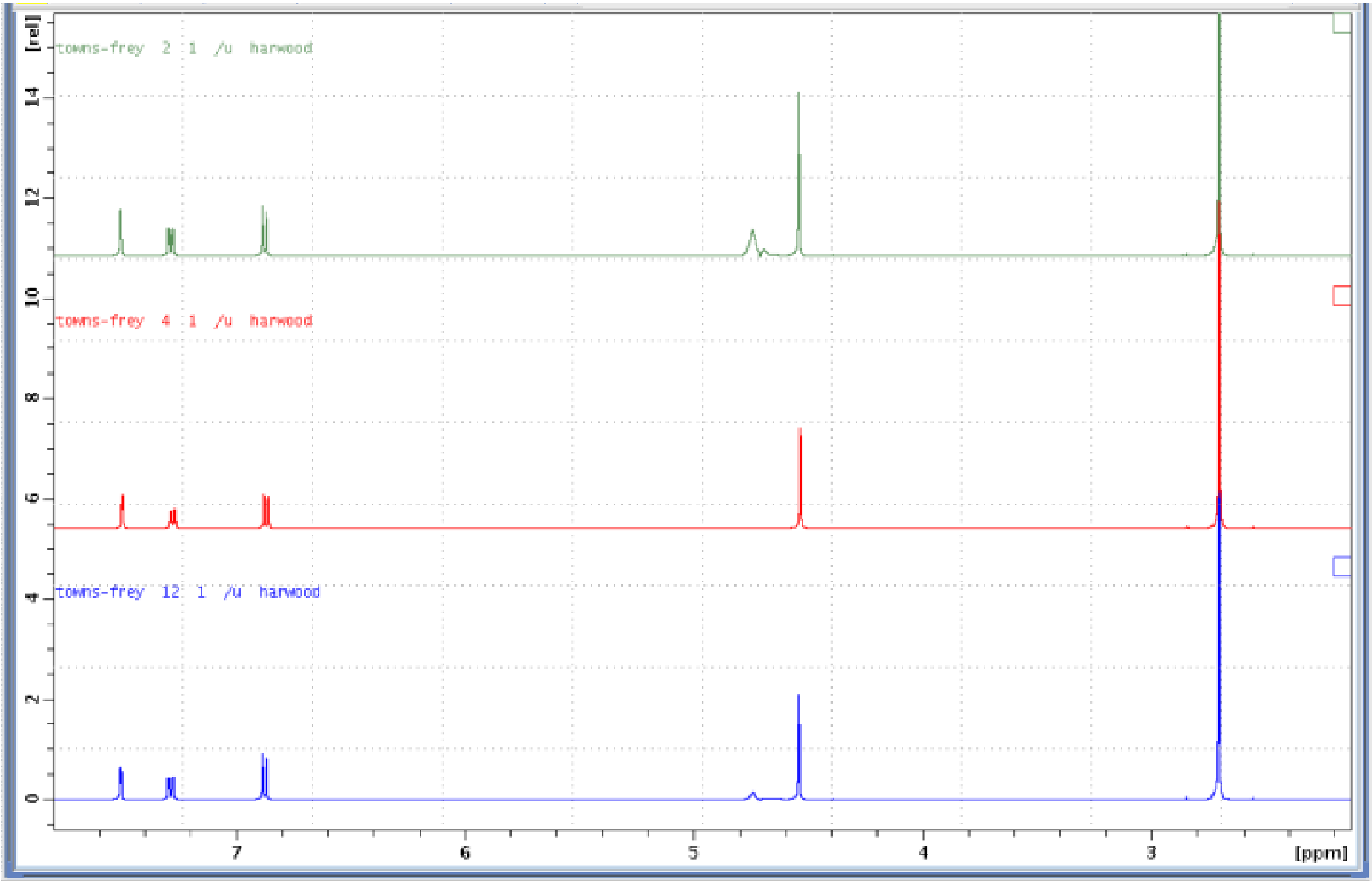


Figure 19: The comparison of all three NMR solution runs.

Unfortunately, this test did not perform as anticipated. Though we did witness a color change, the concentration of 2,4-D used to neutralize the calcium was many times higher than what is used in the field. Initially, we titrated using a 0.0475 M solution of 2,4-D. This is the same concentration stated by the herbicide's mixing instructions. After the addition of over 100 mL of the 2,4-D solution, the 200-ppm calcium solution still was not neutralized. From here we attempted higher concentrations of 2,4-D without any color change until an unknown amount of undiluted 2,4-D solution was added. This is the only time a color change was witnessed. As stated before, this is a much higher concentration of 2,4-D than used in the profession, but an interaction was still witnessed between calcium and 2,4-D.

We attempted to quantify this reaction through back titrations. The goal was to administer a known amount of 2,4-D to a calcium solution. Then this mixture would be titrated with EDTA and the neutralization point will be compared to a titration done without 2,4-D added. However, when carried out, both titrations required the same amount of EDTA to reach the endpoint of the titrations. This data can be seen in Table 5. This could be the result of EDTA having a higher binding affinity to calcium than 2,4-D. This would result in the replacement of any bound calcium with 2,4-D to calcium bound with EDTA.

Table 5: Data from back titrations of EDTA and 2,4-D.

	Initial Buret Reading	Final Buret Reading	Total Volume EDTA Added
No 2,4-D added 10 mL of 199.4 ppm Ca^{2+}	9.50 mL	33.32 mL	23.82 mL
10 mL of .08 M 2,4-D 10 mL of 199.4 ppm Ca^{2+}	13.31 mL	37.89 mL	23.98 mL

4.4 Third Step

We decided to try a third analytical technique and performed conductance titrations. The calcium ion and the deprotonated 2,4-D are oppositely charged particles, therefore, if the two chelate, the conductance of their solutions should decrease. Our next goal was to attempt a conductance titration. We started with a 404.5-ppm calcium solution and used varying concentrations of 2,4-D. The conductance of the calcium solution was measured with a Labquest conductance probe. The conductance of the calcium solution should decrease as 2,4-D is added until all calcium atoms are chelated. Then a rise in conductance should be witnessed with further introduction of the herbicide. Our first titration used a 40% 2,4-D solution to administer to the 404.5 ppm calcium solution and the data is shown in Table 6.

Table 6: Data from the first conductance titration of a 40% 2,4-D solution into a 404.5 ppm calcium solution.

404.5 ppm (50mL) & 40% Ace solution			
Initial (mL)	Final (mL)	Total (mL)	Conductance (µS/cm)
0	0	0	5036
9.81	10.8	0.99	4932
10.8	11.82	2.01	4872
11.82	12.89	3.08	4835
12.89	13.95	4.14	4892
13.95	14.98	5.17	4959
14.98	15.9	6.09	5033

Though this experiment performed as expected, this titration did not include many data points. This led us to attempt another conductance titration using a less concentrated 2,4-D solution. The next test used a 20% 2,4-D solution and the 404.5-ppm calcium solution. During this experiment, the conductance did initially drop, however, the conductance never stopped decreasing. When it fell below 5000 µS/cm, the calcium solution precipitated a white solid and continued to drop without additional 2,4-D. This data is shown in Table 7. To make sure this phenomenon was not the cause of the decreased concentration of 2,4-D, a 30% concentrated solution was made to titrate. Unfortunately, the results for this titration were the same as the 20% concentrated titration. The calcium solution precipitated again starting at 4000 µS/cm.

The chemical identity of the solid is currently unknown. The initial suspicion of the formula was that of calcium hydroxide ($Ca(OH)_2$), but when the solid is separated and nitric acid is added, it is still insoluble. However, when acetone is added, the solid dissolves into solution. This leads us to believe the chemical makeup of the resulting solid may be organic in nature.

4.5 Implications

There is a lot of development left in this chapter. The interaction between calcium and 2,4-D is still not well characterized. This could be answered by determining the chemical identity of the precipitate formed during the conductance titrations. An infrared spectrum and NMR could be taken to identify the chemical structure of the solid. Secondly, titrations with ammonium sulfate added to the 2,4-D solution might show that no precipitate forms. These two tests might provide the information needed to determine why the mixing order is so important.

Table 7: Data from the first conductance titration with 20% 2,4-D into 404.5 ppm Ca2+.

404.5 ppm (50mL) & 20% Ace solution			
Initial	Final	Total	Conductance (μS/cm)
15.99	16.89	3.21	5291
16.89	17.96	4.28	5235
17.96	19.00	5.32	5202
19.00	20.01	6.33	5171
20.01	20.99	7.31	5145
20.99	21.89	8.21	5133
21.89	22.90	9.22	5120
22.90	23.99	10.31	5108
23.99	24.93	11.25	5094
24.93	25.93	12.25	5077
25.93	26.96	13.28	5076
26.96	27.97	14.29	5064
27.97	29.00	15.32	5059
29.00	29.99	16.31	5053
29.99	30.91	17.23	5039
30.91	31.92	18.24	5024
31.92	32.90	19.22	5019
32.90	34.01	20.33	5000
34.01	34.96	21.28	4995

CHAPTER 5. CONCLUSIONS AND IMPLICATIONS

5.1 Review of Work and Goals

The goal of this work was to create and adapt laboratory activities for non-major chemistry students. These activities are modeled to be relevant to students through the relevancy model developed by Stuckey et al. (2013). The "individual" domain of the model was focused for these activities utilizing the students' career choices ("vocational" domain). We wanted the activities to touch on real-world experiences or problems to connect to students' established knowledge to new concepts or create a foundation to build off of later. Three laboratory activities were altered including an intermolecular forces activity with waxy leaves, an enzyme kinetics activity with browning potatoes, and a chelation activity involving hard water and a real-world problem in herbicides in need of a solution.

5.2 Intermolecular Forces

This laboratory activity was created to focus on an important content area of chemistry, IMFs. This was made relevant to students through the application of surfactants. The context for this activity was the use of surfactants to completely cover the surface of waxy leaves. This is done to make herbicides more effective. The "individual" domain can be addressed using the familiar phenomenon of beading water. Students' "vocational" relevancy can also be targeted through the agriculture and health science applications of surfactants.

A pilot study was performed for this activity in the fall semester of 2018. A survey was given to those students who participated to determine which aspects of the lab could be improved upon. This led us to change the computer program (from ImageJ to Photo Protractor) that was used to measure the contact angles. In the future, more changes to accommodate students are suggested such as more background reading on the multitude of uses for surfactants. This can help students to recognize the use of these chemical concepts in their careers and their daily lives.

5.3 Enzyme Kinetics

A laboratory activity developed for biochemistry students was adapted to introduce enzyme kinetics to non-major general chemistry students. The activity studied the rate of browning potatoes, which is a reaction between catechol and the enzyme polyphenol oxidase. Students were asked to inhibit this reaction using either a competitive or noncompetitive inhibitor. To change this lab, the amount of data and inhibitors used were changed to best fit a general chemistry course. The number of data points required was reduced and the inhibitors were changed to safer alternatives of the same inhibitor type.

This content was used as a relevant introduction to enzyme kinetics, which is an important topic for the students' future careers in agriculture and health and human sciences. The real-world experience of browning fruits and vegetables is used to connect to the "individual" domain, and the "vocational" domain is also utilized as this material is important to the future courses and careers of these students.

The future work for this activity includes the development of a pilot study. This requires the alteration of the semester's curriculum to include enzyme kinetics, the development of the lab report and procedure, as well as a post activity survey similar to the one used in Chapter 2 (See Appendix A). After this pilot study, appropriate changes can be made to the content both in lecture and the lab.

5.4 Hard Water Chelation

This activity is focused on the real-world effects of hard water. We want to find the mechanism behind the mixing order of 2,4-D herbicide. Professionals mix their herbicide tanks in a specific order: water, ammonium sulfate, and then 2,4-D. Our theory is that the chelation of this herbicide to calcium in hard water makes entering the leaf cells difficult because of the molecule's size. However, when ammonium sulfate is added before the herbicide, 2,4-D could chelate to ammonium and make a smaller complex. Introducing this topic to agriculture students would add another real-world problem for hard water to this laboratory activity.

To address this, we attempted to use NMR to determine if there were any visible reactions between calcium and 2,4-D. Unfortunately, there was no indication of interaction using this method. Next, we attempted different types of titration analyses. The color change titrations showed calcium and 2,4-D can interact, and, to quantify this, we attempted conductance titrations. These titrations resulted in an unknown precipitate forming. Though the chemical formula and structure are unknown, it does dissolve in acetone.

The future work of this activity requires the analysis of this solid. Infrared analysis and NMR could give us the chemical structure of the solid forming from conductance titrations. This could lead to the discovery of why the mixing order is important to the herbicide 2,4-D.

APPENDIX A: ADDITIONAL INFORMATION CHAPTER 2

Intermolecular Forces

Please help us to improve this experiment by providing responses to the questions below. Lab scores will be given for completing these questions.

	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
	1	2	3	4	5	6
This experiment is appropriate for the first week of class, i.e., check-in.					✓	
There was adequate background information given to complete the report.					✓	
Image J was easy to use.					✓	
This experiment gave me a better understanding of surfactants in daily life.					✓	
This experiment relates to the topic of intermolecular forces discussed at the beginning of the semester.					✓	

Figure A.1: Pilot survey given to those students who completed the optional pilot activity.

LABORATORY READING REPORT AND DISCUSSION

Intermolecular Forces

Goals:

- To compare surface properties of plant leaves with/without epicuticular wax.
- To compare the wettability of deionized water and surfactants.
- To use Photo Protractor to measure contact angles from photo images.
- To understand how surfactants change the intermolecular interactions between water and nonpolar surfaces.

Molecules interact with each other and their environment (i.e. the container they are in or the surface they are on) through intermolecular forces (IMFs). Intermolecular forces describe the attractions between molecules. There are different types of intermolecular forces, such as ion-dipole, hydrogen bonding, dipole-dipole, ion induced dipole, and London dispersion.

Intermolecular forces can be very weak resulting in the molecules being held together loosely (like we see in gases) or they can be quite strong resulting in molecules that are tightly held together (like in liquids and solids). Strong intermolecular forces between molecules lead to low vapor pressures, high boiling points, high viscosities, and high surface tension. The strong intermolecular forces that exist between water molecules are a good example.

At room temperature and standard pressure, water molecules are so strongly attracted to each other they prefer to stay close together in the liquid phase instead of floating away individually into the gas phase. These strong attractions mean that a lot of energy is required to force the water molecules to leave the liquid phase and enter the gas phase, resulting in a high temperature for boiling. We can also see the strength of the intermolecular forces between water molecules when we observe a drop of water on a freshly waxed car. The polar water will bead up and shrink away from the nonpolar, waxed surface of the car. Metaphorically speaking, the water molecules would prefer to interact only with each other and they literally shrink away from the surface that they find less attractive.

In this experiment, you will be observing water molecules on nonpolar surfaces. You will explore ways to alter the interactions that naturally arise between a nonpolar surface and polar water molecules. For this lab, we will be using the waxy coating on a leaf as our nonpolar surface.

Over millions of years, plants have developed structures to protect themselves from the environment. One of those structures is epicuticular wax that covers the surface of some leafy plants, such as collard greens. This wax helps the plant protect itself from dehydration, invasion by harmful pathogens and insects, as well as exposure to the sun. The waxy coating also repels water. The raindrops bead up on the leaf and run off of the leaf carrying away dirt and bacteria. Unfortunately, the wax coating can also prevent effective application of water-based agrichemicals such as herbicides, pesticides and fungicides by providing a barrier to these liquids.

The hydrophobic (water fearing) property of the leaf's waxes is responsible for the beading of the water.

The waxes of plants owe their hydrophobicity to the non-polar chemical that make up the structure of the wax. The epicuticular waxes often contain a mixture of long chains of hydrocarbons with lengths beTween® 20 and 40 carbons, alcohols, ketones, aldehydes and fatty acids. Figure 1 shows an example of the hydrocarbon icosane.

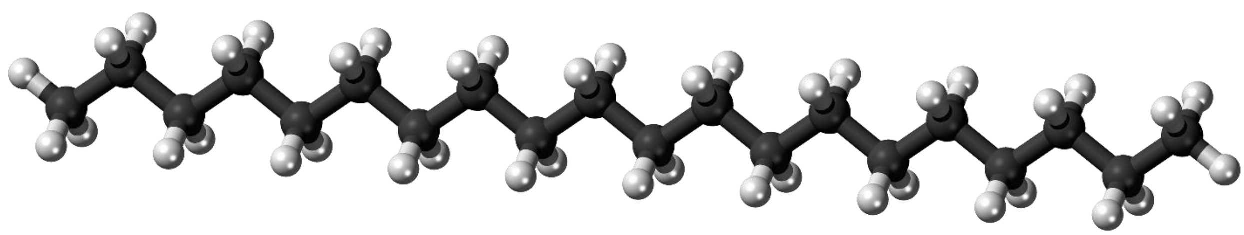


Figure 20. Icosane has 20 carbons.

Chemical additives or agrichemical products exist to weaken the IMF's of the water, and allow for an increase in the wetting of waxy plants. You will investigate two products with these properties: Palmolive dishwashing liquid and Tween® 20. These products act as surfactants (due to their chemical structure). Each product owes their properties to a hydrophilic (*water loving*) head and a hydrophobic (*water fearing*) tail. Tween® 20 is shown in Figure 2 below for reference, as well as a simplified model of a surfactant.

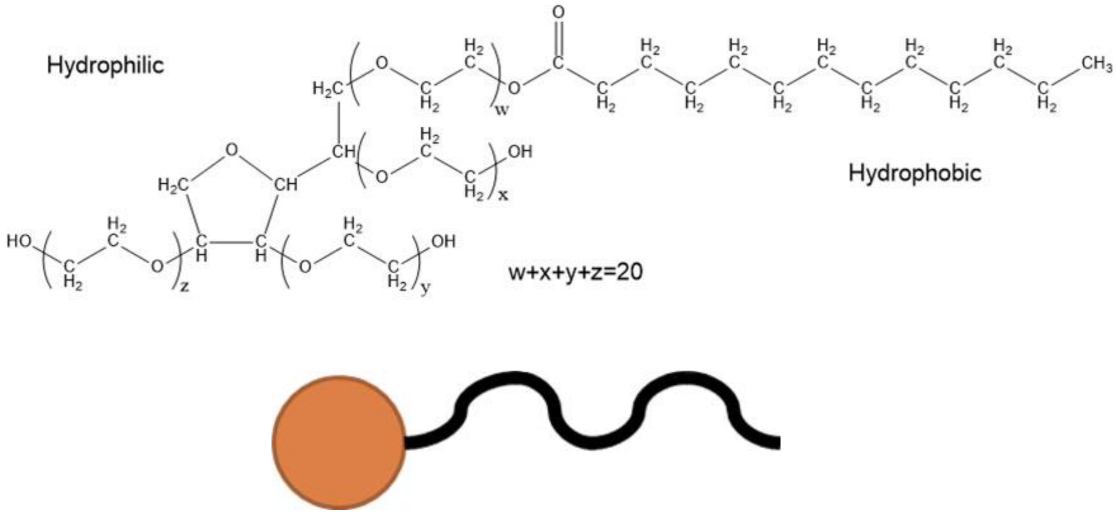


Figure 2. Molecular structure of Tween® 20 (top) and a simplified sketch of the surfactant (bottom).

Quantifying Wettability

A drop of liquid on a solid surface owes its dome-like shape to a combination of three forces acting on the drop: 1) the surface tension between the solid surface and air, 2) the surface tension of the drop and air, and 3) the surface tension of the solid-drop interface. One will encounter high beading when the surface tension (the amount of force that holds the surface of a liquid together) of the liquid outweighs the forces attracting the liquid to the surface. Therefore, instead of spreading out, the liquid remains in a droplet because it is more attracted to other molecules of itself than to the molecules of the surface. Cohesive forces hold the drop of water together.

Contact angles are one way to measure the extent of liquid beading on a surface. Figure 3 shows the relationship between contact angle and the "beading" of liquid. Contact angles are a measure of the interaction between molecules in the liquid and molecules on a surface. A very high contact angle ($\Theta > 110$) means low interaction or low intermolecular forces between the surface's molecules and the liquid molecules. The drop beads and does not wet the surface. Conversely, a liquid that spreads across a surface would have a very small contact angle meaning that the drop is wetting the surface.

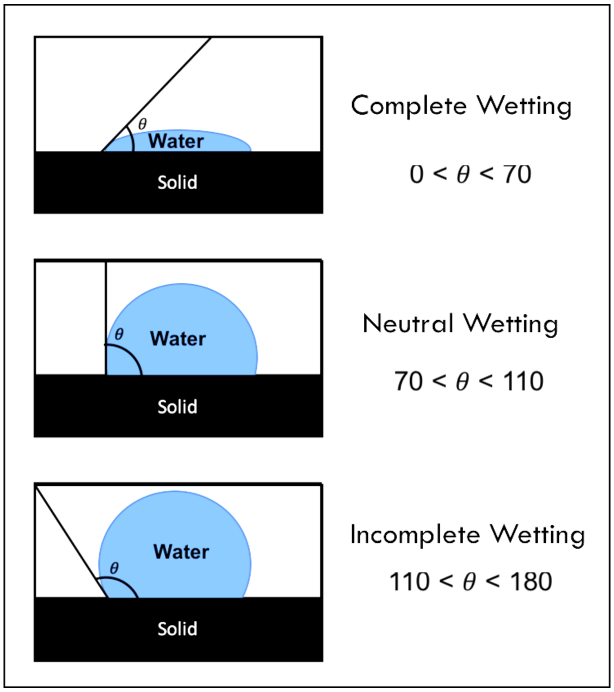


Figure 3. Interpreting the contact angle. The more a liquid spreads or wets a surface, the magnitude of the contact angle decreases.

https://commons.wikimedia.org/wiki/File:CapillaryPressureContactAngle.png

Procedure

You will perform this procedure with a lab partner. You or your partner will use a smart phone and the Photo Protractor app to measure contact angles for solutions on leaf cuttings. If you have not already done so, download the app on your phone.

Materials

You will remove the epicuticular wax and/or add a surfactant to the surface of a leaf water to study the effects on the contact angle. You will do this by measuring the contact angle of drops of three different liquids (deionized water, 0.5% dishwashing liquid and 0.5% Tween® 20: each liquid contains red dye so that you can easily see the drops) on a leaf cutting with the epicuticular wax intact, and on a leaf cutting with the wax removed. Tween® 20 (polyethylene glycol sorbitan monolaurate**)** and dish soap are surfactants and emulsifying agents

Work is performed in groups of 2 students. You and your lab partners will need the following materials:

From your drawer:

- forceps
- 3 – small test tubes, clean and dry
- 3 – medicine droppers, clean and dry
- test tube support
- ruler

From the reagent bench:

- 1- leaf cutting template
- 1- pair of scissors (share with another group)
- 1 - roll double sided adhesive tape (share with class)
- 1 - paint brush (share with another group)
- Deionized water with red food dye
- 0.5% Tween® 20 with red food dye
- 0.5% Dishwashing liquid with red food dye
- 1 - collard green leaf

Wear gloves while handling the collard greens. You must handle the greens with care. The mere friction and oils on your fingers will remove the epicuticular wax.

Preparing Leaf Cuttings

1. Put on a pair of gloves.

2. Obtain a collard green leaf and a leaf-cutting template. Carefully, without touching the leaf surface cut **three** 2 in. by 2 in. square pieces of the leaf. Be sure to avoid large leaf veins and excessively curled areas because the leaf must lie flat on the bench top.

3. Cut an 8-inch long piece of double-sided tape and affix along the edge of the bench top. Place another 8-inch piece of tape parallel to the first piece. See Figure 4 below.

Figure 4. Two 8-inch pieces of double-sided tape on the edge of the bench.

4. Using your forceps, place a leaf cutting on the tape along the edge of your bench. You want the leaf cutting to lie as flat as possible. See Figure 5.

Figure 5. Position Leaf Cutting on Edge of Benchtop.

5. Gently brush the right side of the leaf cutting with the paintbrush to remove the wax until the surface becomes glossy (about 20 strokes up and down and 20 strokes from midline to the right). Be careful. You only want to brush the **right** side of the leaf.

Brush right side of leaf.

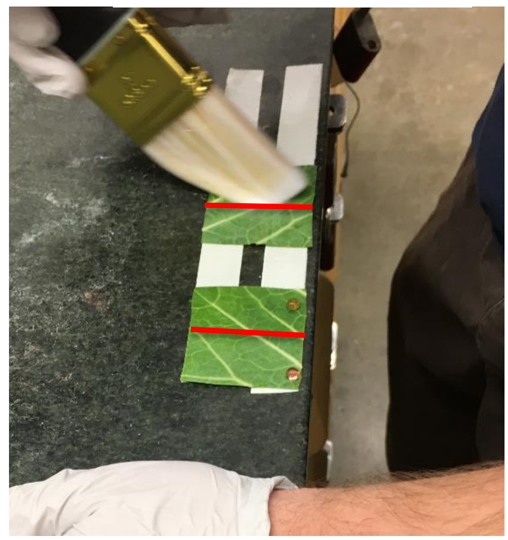


Figure 6. Brush the right side of each leaf cutting to remove wax.

Preparing Images of Droplets on Leaves with and without Wax

1. Label a clean and dry small test tube "DI" for deionized water.

2. Transfer 20 drops of deionized water with red food dye into the test tube.

3. With a clean dry medicine dropper, place one drop of the dyed water on the edge of the untreated (left) side of the leaf cutting and another drop near the edge of the brushed (right) side of the leaf. See Figure 7 below.
   Be sure to place the droplets on flat sections of the leaf. Avoid veins and curly edges

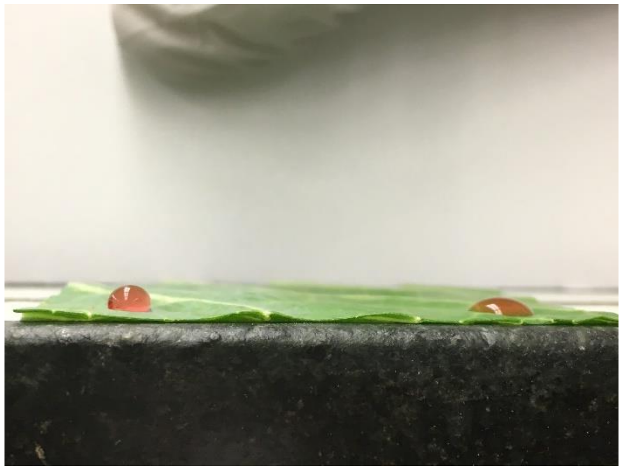


Figure 7. Droplets on edge of leaf.

4. Using your smart phone, take a photo of both droplets on the leaf cutting's surface for comparison of contact angles before and after removal of epicuticular wax. Take the pictures at eye level and horizontal with the benchtop. Placing a sheet of plain paper as a backdrop may help increase the visibility of your droplets. See Figure 7.

5. Repeat the procedure by placing another leaf cutting on the tape about ¾ - 1 inch from the first cutting. Brush the right side of the cutting as you did before and place a drop of 0.5% Tween® 20 solution on each side of the cutting. Repeat again with 0.5% dishwashing liquid on your other leaf cuttings. Use a new test tube and a new medicine dropper each time in order to avoid cross contamination.

6. Measure contact angles of drops using app for iPhone or Android phone. Your TA will provide instructions.

Clean up and Waste Disposal

Discard all solutions used during this experiment down the sink.

Discard the leaf cuttings and tape in the trash.

Return the leaf cutting template, tape, paintbrush and scissors to your teaching assistant.

Wash your glassware and return it to your drawer.

Keep your splash goggles on until you are ready to leave the lab.

DATA

Record your data in Table 1 of the report form. You must give the table an appropriate title.

DISCUSSION

1. How does the epicuticular wax affect wettability? Use your data and intermolecular forces arguments to explain your answer.

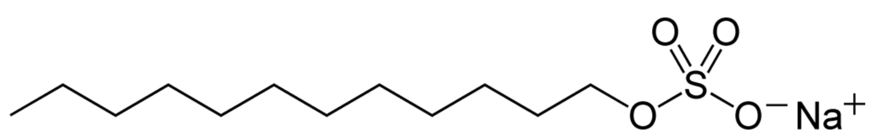
2. How does the presence of a surfactant affect wettability? Use your data and intermolecular forces arguments to explain your answer.

3. a. Draw the Lewis structure for water and show any partially charged regions of the molecule.

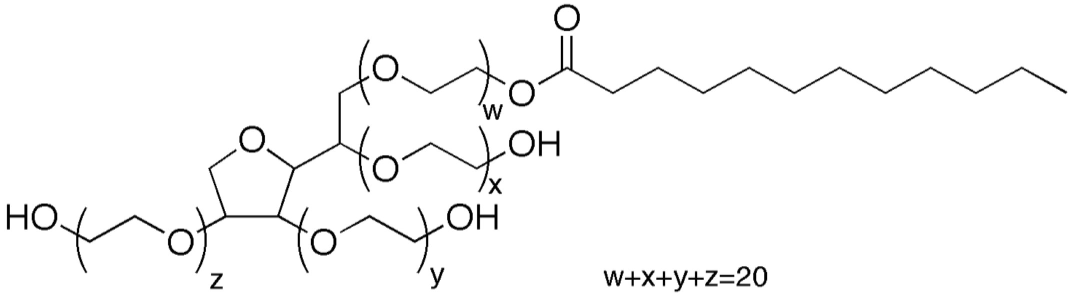
   b. Describe the type of intermolecular forces exhibited among water molecules.

4. Would a drop of a non-polar liquid have a high ($x>90^o$) or low ($x<90^o$) contact angle on the leaf's surface? Why?

5. You will use two different surfactants this experiment. The surfactant used in Palmolive dishwashing liquid is sodium lauryl sulfate. See the structures of sodium lauryl sulfate and Tween® 20 below. Label the hydrophilic and hydrophobic ends.



Sodium Lauryl Sulfate



Tween® 20

6. Studies show that the sodium lauryl sulfate found in dishwashing liquid is a better wetting agent than Tween® 20. Does your data support this claim? Explain using your data.

The Lab Report

Your TA will provide the lab report. You and your partner will complete the lab report turn in **one report** at the end of lab.

Each member of the group will receive the same grade for the report.

Attach your individual observations (pink duplicates from lab notebook) to the report form.

References:

This laboratory experiment was adapted from Chiu et al.

1. Y.C. Chiu, M. A., Jenks, M. Richards-Babb, B. B. Ratcliff, J. A. Juvik, K. M. K, Demonstrating the effect of surfactant on water retention of waxy leaf surfaces, *J. Chem. Educ. 2017 94, 230-234*

REPORT FORM

Title: ____

Work Done and Report Prepared by: ____

Lab Section:___________________________________ Date:_____________

GOAL(S):

DATA

Table 1.

Droplet Identity	**Leaf Contact Angle with wax (degrees)**	**Degree of Wettability (Complete/ Neutral/ Incomplete)**	**Leaf Contact Angle without wax (degrees)**	**Degree of Wettability (Complete/ Neutral/ Incomplete)**
Deionized water				
0.50% Tween® 20				
0.50% dishwashing liquid				

DISCUSSION QUESTIONS

1. How does the epicuticular wax affect the contact angle? Use your data to explain your answer.

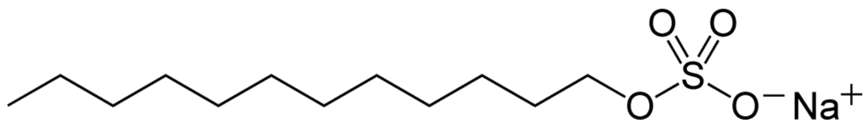
2. How does the presence of a surfactant in aqueous solution affect the contact angle? Use your data to explain your answer.

3.
   a. Draw the Lewis structure (including all lone pairs of electron) for water and indicate any partially charged regions of the molecule.

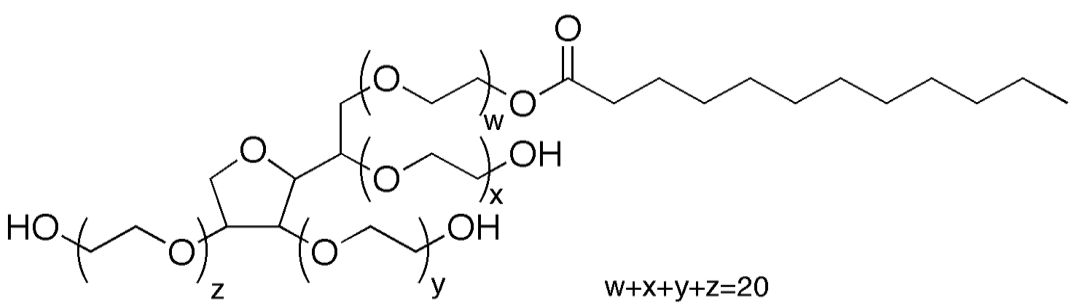
   b. Describe the types of intermolecular forces exhibited by water.

4. Based on your data, would you expect a drop of a **non-polar liquid** to have a high ($\Theta > 90^o$) or low ($\Theta < 90^o$) contact angle on the leaf's surface (with epicuticular wax)? Why?

5. You will use two different surfactants this experiment. The surfactant used in Palmolive dishwashing liquid is sodium lauryl sulfate. See the structures of sodium lauryl sulfate and Tween® 20 below. **Circle** and **label** the hydrophilic and hydrophobic ends.



Sodium Lauryl Sulfate



Tween® 20

6. Studies show that the sodium lauryl sulfate found in dishwashing liquid is a better wetting agent than Tween® 20. Does your data support this claim? Explain using your data.

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