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Polymer chemistry education to increase student awareness of plastic pervasiveness and environmental impact

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Polymer Chemistry Education to Increase Student Awareness of Plastic Pervasiveness and Environmental Impact

by

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Dedication

To every young girl who saw a scientist and wondered if she could be one, too.

To my nieces and nephews Madeleine, Warren, Colten, Jager, Matteo, Lucianna, Augustine, and Cecilia, in the hopes that this can be an example that dreams can come true with hard work and determination.

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Abstract

A polymer-pollution-focused laboratory sequence was written to teach general chemistry concepts in a course for pre-service elementary teachers. Students experienced the difficulties related to polymer pollution clean-up and made bio-based materials to see possible alternatives. In order to determine whether this laboratory sequence changed student understanding of the importance of polymers and their environmental impact, student opinions were gathered with pre/post-course sequence surveys, observations, post-laboratory surveys, and focus group interviews. These same data collection methods were also used to determine the likelihood that the pre-service elementary teachers would teach these polymer and environmental laboratories or their concepts in the future. This study provided pre-service teachers with the knowledge and curriculum to teach about polymers and their subsequent pollution and then determined the effectiveness of the course material.

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Chapter 1: Introduction

Review of Literature

Polymers are an important part of our everyday life, making up the plastics, adhesives, and fibers we rely on (Ford, 2017). Despite their pervasiveness, polymers are not thoroughly covered in university curriculum (Ford, 2017; Carraher & Droske, 2008). Polymer education is notably lacking in science education literature (Hodgson & Bigger, 2001). Creating courses or curricula modules that focus solely on polymers could help solve this problem (Ford, 2017; Hodgson & Bigger, 2001). However, adding polymer chemistry to courses could require the removal of current material, which could create other gaps in student knowledge. Instead, teaching chemical principles through the lens of polymer examples could be a more effective way to incorporate polymers into curriculum (Hodgson & Bigger, 2001). Utilizing "real-world" examples in class engages students and shows the importance of science education (Carraher & Droske, 2008). One significant example of polymers' effect on the everyday life of students is plastic pollution, which has become increasingly problematic (Schnurr et al, 2018).

Plastic pollution is a well-known problem, as it has become the focus of news broadcasts, commercials, and numerous studies. A 2014 study used net tows, where a net is towed behind a boat to pick up debris, and an oceanographic model of ocean debris distribution to estimate the weight density of plastics and their global distribution (Eriksen et al, 2014). Their findings estimated that there are 5.25 trillion pieces of plastic floating on the ocean's surface with an estimated weight of 268,940 tons. For reference, that is about 215,152 Honda Civics (2018 base model). Of these floating plastics, Eriksen et al. (2014) found that 87% (by weight) were around five millimeters or larger. However, when considering the number of plastics, these only account for 7% due to the plastics breaking down into microplastics in the sun and waves (Eriksen et al, 2014). That said, it is important to note that Eriksen et al.'s study is six years old, so the amount of plastic has almost certainly increased.

Data collected by Eriksen et al. (2014) that shows 268,940 tons of ocean plastic becomes even more daunting when put into the perspective of an article by Cressey (2016), which reports that floating plastics are a small fraction of annual plastic pollution. While there are debates as to exactly what extent these plastics are harmful to animals and other organisms, there is no denying the amount of plastic these creatures consume. Looking at data about fulmar seabirds, 90% of dead birds that washed ashore in the North Sea had ingested plastic (Cressey, 2016).

With these huge numbers, it becomes important to implement plastic pollution education in classrooms. Derraik (2014) emphasizes that education is a powerful tool, as students can bring awareness to their communities and instill change. Legislation and efforts to reduce pollution are often ignored, but a general public with environmental education can ensure that businesses and governments address these problems with their dollars and votes. If communities become aware of plastic pollution issues and are willing to change, educating the public can make a significant impact on pollution problems (Derraik, 2014).

Using pollution to teach polymeric properties coincides with environmental education, a branch of scientific education that has grown dramatically over the past 25 years (Ardoin et al., 2018). There is a need for analyzing course outcomes in these classes, specifically regarding environmental attitude, knowledge, and agency. Elementary and middle school students are often the target population for this environmental education research, while only 34% of the environmental education papers reviewed programs for high school students. This leaves an opportunity to expand environmental education to older students.

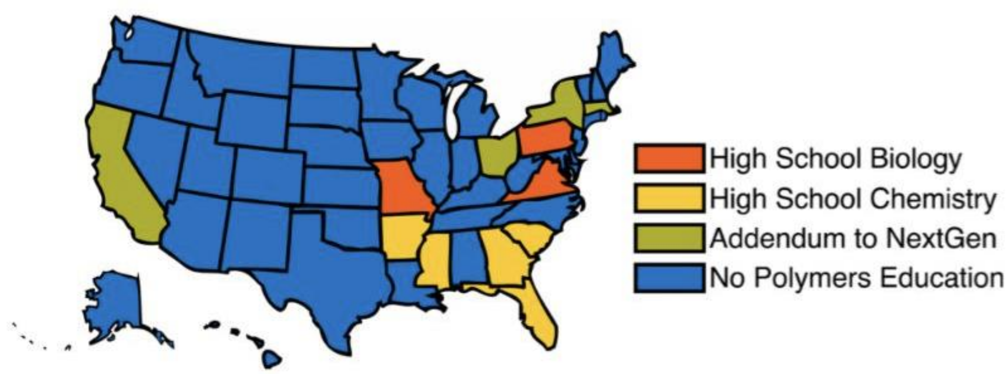
In recent years, the American Chemical Society (ACS) Committee on Professional Training (2015) added macromolecules and polymers to the required curriculum for an ACS-certified chemistry degree. In response to this, there have been several efforts to increase polymer education through course implementation at multiple academic levels (Furgal, 2018; Moore & Stanitski, 2017). At the undergraduate level, an introductory polymer course was created by Joseph Furgal (2018) for chemistry students at University of Detroit Mercy. To ensure that students understood concepts of polymer chemistry and their applications, a variety of teaching methodologies were used. To teach polymer applications, lectures consisted of slideshows, research publication videos, and recent primary sources so students could better understand material and follow new topics in polymer research. Avent et al (2018) took an interactive approach to this by combining polymer laboratories with a flipped classroom. Students had a 10-minute lecture video outside of class and followed up with group-based interactive learning during class. Polymer-based laboratory units were added to this chemistry course that covered plastic recycling, creating soap, and other everyday topics.

Some schools have chosen to incorporate polymers into general chemistry courses to comply with ACS stipulations without creating more classes (Ford, 2017; Hodgson & Bigger, 2001; Moore & Stanitski, 2017). The focus was simplified by applying polymer concepts to existing chemistry topics in a way that is relevant to everyday life and cutting-edge research. The curriculum used this strategy to teach these concepts from a new perspective. The end goal was that the course would help students pay attention and better prepare students for courses in other departments. While qualitative feedback indicated this program was successful, there was no quantitative study done to assess the effectiveness of the curriculum.

While ACS had required polymer education for their certified undergraduate degrees, K-12 public education is still lacking when it comes to polymer education of any kind. The Next Generation Science Standards (NGSS), a set of science education standards used across 26 states (recently updated from 25 as listed in this paper), does not include the term "polymer" anywhere (Cersonsky et al, 2017). Some states do have the term "polymer" in their science curriculum, but only one includes it in education before senior high (see Figure 1). California, the exception, includes polymers in their junior high curriculum, although they also implement an addendum to NGSS as state-specific standards.

Figure 1

Polymer Education Map



Note. The eleven States that include polymers in their senior high education standards, with what time and course they were introduced. From "Augmenting Primary and Secondary Education with Polymer Science and Engineering" by R. K. Ceronsky, L. L. Foster, T. Ahn, R. J. Hall, H. L. Van der Lana, & T. F. Scott, 2017, *Journal of Chemical Education, 94*(11),pp. 1639-1646. Copyright 2017 by The American Chemical Society and Division of Chemical Education, Inc. Reprinted with permission.

Of the 26 states using NGSS standards, only 11 states include polymers in their senior high education. Figure 1 indicates the earliest grade level that polymers are introduced and in what course. The category “Addendum to Next Gen” indicates that the state introduces polymers in a curriculum addendum to NGSS, rather than a specific course. To address this issue, University of Michigan graduate students created an outreach program that traveled to various economically disadvantaged K-12 schools and taught modules targeting each grade level (Cersonsky, 2017).

These modules were based on the NGSS standards used in Michigan to ensure content is appropriate for each grade level. The lesson plans include information about polymer properties, recycling, and polymers in medicine, each paired with a couple of activities. Program success was evaluated by anonymous surveys of both teachers and volunteers and had positive feedback. Teachers noted that the modules fit into their curriculum, and 87% were interested in having the program return (Ceronsky et al, 2017).

Similar to polymer education, environmental education has also increased in recent years at all academic levels (Tamburini et al, 2014). For example, a course was created at Wichita State University (WSU) for seniors and graduate students to bring attention to recycling. The 600-level elective, focused on increasing engineering students’ interest in recycling, taught them the process of recycling and contributed to the developing culture of recycling at WSU (Asmatulu & Asmatulu, 2011).

At the undergraduate level, multiple courses have been created to improve students’ environmental literacy and promote activism (Ford, 2017; Hodgson & Bigger, 2001; Bloom & Holden, 2011; McDonald & Dominguez, 2005). One such course for future elementary teachers also focused on six components to improve critical thinking and active learning skills.

Professionalism, student reflection, class participation, collaborative hands-on activities, online discussion, and student involvement in community environmental actions are the six components that were over 70% effective in promoting the belief that the students could make a difference when it comes to environmental issues (Kazempour & Amirshokoohi, 2013). At the K-12 level and the undergraduate level, a summer outreach program was created in line with NGSS to teach scientific principles through the lens of relevant topics in the lives of students. The focus on environmentally friendly plastics was chosen based on the growing issue of sustainability and opportunity for multidisciplinary activities . This program, Paper to Plastics (P2P), allowed students to learn in a research environment, encouraging enthusiasm for STEM fields in students across varying disciplines and age groups (Tamburini et al., 2014).

Learning about environmental issues can result in a recurring problem for students: ecophobia (Tamburini et al., 2014; Bloom & Holden, 2011). Ecophobia is the sense of hopelessness, anxiety, and fear (often resulting in apathy) that students often develop when learning about environmental issues (Bloom & Holden, 2011). This happens when students become aware of the magnitude of the problem and feel that they aren't able to contribute to a solution. This effect is likely magnified in students with non-science majors. While ecophobia is a common problem in environmental education, several methods have already been developed to combat it. Bloom and Holden (2013) encountered ecophobia while teaching a biology course for nonscience students that focused on relating current events to science topics. To combat ecophobia in his classroom, Bloom and Holden developed "Five Small Steps to Reduce your Environmental Footprint," a project where students experience the process of science hands-on and give them agency of their environmental impact. The students identified five personal behaviors that negatively affect the environment and determined what could be changed to be more eco-friendly. This method was successful, as the students collectively came up with 95 differentiable actions between the 132 that participated and changed their attitudes about environmental issues (Bloom & Holden, 2013).

Another approach to combating ecophobia and creating a positive environmental curriculum is the inclusion of service learning in course curriculum, which allows students to feel some responsibility to address environmental issues and learn scientific literacy more effectively (McDonald & Dominguez, 2005). This assignment, termed "The Action Team Service Project," was given to an elementary science methods class that follows National Science Education Standards (NSES). The project was a favorite among students, some of whom continued to be involved in their cause after the class ended (McDonald & Dominguez, 2005). Students were able to improve science literacy and awareness of environmental issues without the negative effects of ecophobia via this method.

While there is substantial course material for polymer chemistry curriculum, the effectiveness of these courses is rarely evaluated (Furgal, 2018; Moore & Stanitski, 2017). When there is an evaluation, it is often done quantitatively, focusing on numeric data. This may look like test scores, course grades, or student responses recorded as ratings on a numeric scale. Qualitative student reflections and evaluations provide a different image of the curriculum success, as they are directly written by students and leave less room for interpretation.

An example of this lack of evaluation is Moore's and Stanitski's (2017) implementation of polymer education in a general chemistry course. While a curriculum, textbooks, and methods are described for polymer education, there is no data about the student learning outcomes and student opinions of the course. The lack of data about student performance or interest means that there is no definitive measure of increased student knowledge of polymers or improved students' scores in chemistry. The conclusion states that polymers can be "introduced and integrated successfully into general chemistry curriculum," but does not cite student grades or feedback (Moore & Stanitski, 2017, p. 1606). This makes it difficult to know the actual effectiveness of the program.

Purpose of the Study

To fill this gap and create a stronger bridge between polymer chemistry and environmental education, a series of activities were created for Chemistry 101: Chemistry for Elementary Teachers at Eastern Michigan University in the fall of 2019. These labs focused on delivering important general chemistry concepts through the lens of polymer science and its subsequent environmental issues. The modules used the Next Generation Science Standards from kindergarten through fifth grade as the basis for each laboratory so students can teach them with minimal edits in their future classrooms. Thorough qualitative analysis was conducted in the form of surveys, interviews, and observations. This not only combines the strengths of both polymer education and environmental education but helps and encourages future teachers to teach these concepts in their own classrooms.

Guiding Research Questions

Guiding research questions are a tool for qualitative researchers to focus on their areas of interest for the study (Miles et.al., 2019). For this study, we focused on student knowledge of the importance and environmental impact of polymers. Tamburini et al. (2017) and Asmatulu and Asmatulu (2011) both find that environmental education is on the rise and the curriculum can effectively change students' attitudes about environmental issues. Based on this, we wanted to see if pollution-focused environmental education would improve awareness as the plastic problems grow. In addition, we wanted to know how this knowledge and classroom experience affects the curriculum of these future teachers. As the curriculum was based on NGSS state standards, students can directly teach the material. We evaluated students' attitudes about whether they thought the environmental pollution education was worth teaching and if they would use the labs they did throughout the semester. The two overarching research questions that guide the project are as follows:

1. How effectively do undergraduate polymer laboratories for pre-service teachers improve their understanding of the importance and environmental impacts of polymers?
2. What effect do such labs have on pre-service teachers' intentions to include polymer-focused environmental education in their future classrooms?

Chapter 2: Methods

Study Participants

This study was conducted during the fall semester of 2019 at Eastern Michigan University in Ypsilanti, Michigan. There are 14,872 undergraduates and 2,942 graduate students enrolled in the university. The student population is diverse in age, race, and major. The participants of this study were a mix of sophomore, junior, and senior year pre-service elementary teachers enrolled in Chemistry 101: Chemistry for Elementary Teachers. They were chosen through purposeful sampling, where researchers choose the participants based on characteristics, which is often used in qualitative research (Palinkas et al., 2013). This class was chosen for the study with the intent of preparing future elementary educators in polymer pollution education. One student dropped out of the course before the study was complete.

IRB and Ethics

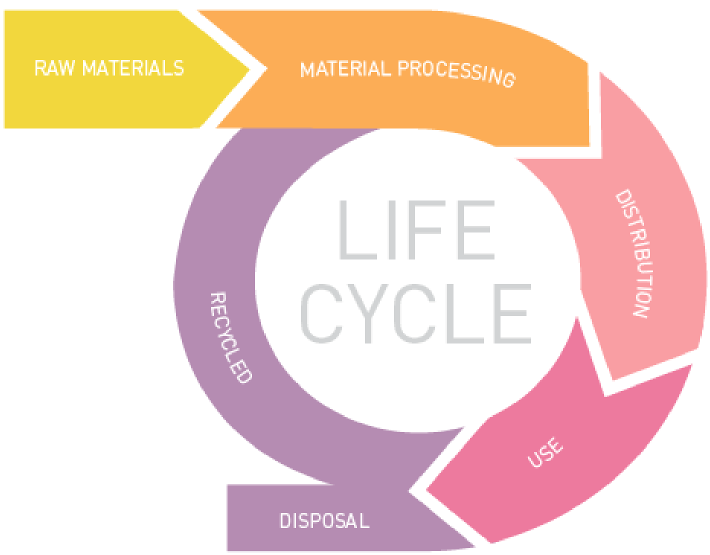
All interview and survey questions were approved by the IRB (Institutional Review Board) in September 2019. The IRB Acceptance Letter is in Appendix A. Observations, pre-/post-course surveys, post-laboratory surveys, lab reports, and focus groups each had its own consent form that was explained and completed ahead of time, which can be seen in Appendices B, C, D, E, and F, respectively. Student participation in all data collection was voluntary. Course credit was given for focus group participation. As all surveys were given as a paper copy, all answers were transcribed to Google Sheets and pseudonyms were used for student confidentiality.

All students were given the choice to consent to classroom observations. They also were given the options to participate in filling out surveys and focus group discussions. Students were made aware of the study at the beginning of the semester through a concise explanation of each type of data collection, how it would work, and why it was needed. They were also given an explanation of participant confidentiality. This confidentiality was ensured by giving each student a pseudonym for data storage and analysis. Written consent was obtained for each type of data collection. Consent forms and data were stored with the researcher and treated with strict confidentiality. As Dr. Johnson was the professor for the course, she was unable to learn student pseudonyms until the course was completed.

Additional Context

Figure 2

Life Cycle of Polymers



Note. Life cycle of polymers and plastics from raw materials to recycling or disposal. From Pratt CSDS, n.d., csds.pratt.edu. Reprinted with permission.

The laboratories created were based on the life cycle of polymers (see Figure 2) in order to create an understanding of where polymers come from and where they go when disposed of or recycled. It can be quite easy to forget about this life cycle when using polymers in day to day life. The curriculum is designed for students to experience the beginning and end of this cycle so they become more aware of the impact polymers have on the environment and what alternatives we can use.

Environmental education for elementary students is frequently done by using interactive and approachable activities. To best prepare pre-service elementary teachers for their own teaching experience, the laboratories in this study are based on NGSS standards for kindergarten through fifth grade. This was designed with the goal of showing the participants how to incorporate environmental education into required standards. It is worth noting that of the states that included polymers in their standards, four added the subject to existing NGSS standards I utilized.

Laboratories

The laboratory sequence designed for this course consists of five experiments, each of which are discussed separately in the following sections. This sequence is organized such that students start with an introduction to the problem of plastic pollution, experience its difficulties, then begin to work on solutions. The emphasis on solutions is in place to try to reduce the likelihood that ecophobia could easily arise from learning about a problem as extensive as plastic pollution.

Why Do We Need Better Plastic?

The laboratory sequence for this study began in the second experiment for the course, which is found in Appendix G. The *Properties of Matter* set of experiments included a section titled “Why do we need a better plastic?” which was modified from “Polymers for the Planet” curriculum (Teaching Channel & Boeing, 2016). The unit started with a “company letter” asking students to help design a new biopolymer to introduce the topic of plastics. To start thinking about that task, students wrote their opinions on plastic issues. There was a read and response section featuring articles from both Scholastic and Nature to demonstrate pollution education at both elementary and collegiate levels. This introduced students to the problems of plastic pollution and microplastics to prepare them for the laboratory in the next part of the study.

Why Do Plastic Containers Have Those Different Numbers Stamped on Them?

Experiment 4 focused on density, with parts 2 and 3 included in the study. These are in Appendix H. After students became more familiar with the idea of plastic/microplastic pollution, I wanted them to learn more about the polymeric material and experience the effect of its pollution. Part 2, “Why do plastic containers have those different numbers stamped on them?” had students observe plastic from every Resin Identification Code (RIC) that is used to sort recycling. These RICs identify which polymer plastic resin was used to manufacture that product. Although RICs are not required by the federal government, they have been in use since 1988 and enacted into legislation in 39 states (Keller & Heckman, 2020).

Students labeled these RIC polymer types from materials they use in their own daily lives, from Starbucks coffee to-go cups to plastic bags and soap bottles. Comparing these plastic types and listing how they are used was part of this assignment so students could get a better understanding of how prevalent plastic polymers are in their lives. Students were also presented several additional resources about RICs, plastics they use, and related issues. This activity was modified from “Polymers for the Planet” by the Teaching Channel and Boeing (2016). All plastic samples were taken from the researchers' homes or the recycling stations available on campus.

Part 3 of this experiment, "How can we sort plastics if they aren't coded?" was modified from Enrique Hughes et al.'s (2001) "Floating Plastics" laboratory. This lab section was split into two activities, one that focused on confirming densities of known plastic pieces, and the other that utilized those skills to determine the identities of unlabeled microplastics. Each plastic RIC has a different density, depending on what polymer it is. Students were given a diagram, seen in Figure 1 in the lab report in Appendix H, that listed the density of each RIC and all seven solutions used in the activity. The RIC number 3, polyvinyl chloride (PVC), is not included in this chart because its density can vary among different products (Hughes et al., 2001).

In the first activity, students were given samples of each plastic RIC that were about three-square centimeters in size. To confirm the density, students placed their piece in a series of solutions to determine if it sank or floated. If the plastic did float, it was cleaned and placed in the next solution until students found the solution it sank in. This indicated that the plastic is denser than the solution, confirming or disputing the RIC placement on the diagram. Students recorded the results of this activity (whether it sank or floated) in a provided table (also seen in Appendix H) that clearly showed the trend of RIC densities. Once completed, students then chose one unknown plastic sample, also around three-square centimeters in size, and followed the same procedure to determine its identity. In the lab report, students were asked to explain their choice by providing evidence from their experiment and supporting their claim with data from diagram in Appendix H. In addition to preparing students for the next activity, this first activity intended to help students visualize these polymer densities in a different way.

The second activity in Part 3 was much more difficult and tedious, as it was designed for students to experience just how difficult it can be to retrieve microplastics from the ocean and identify them for recycling purposes. Plastics of different colors and shapes sourced from the researchers' homes and university recycling centers were cut up into pieces of 0.5 cm^2 or less to simulate microplastics. Ocean microplastics are typically less than five millimeters long, but this was determined to be too difficult to filter and rinse for the activity to fit a K-5 curriculum (National Oceanic and Atmospheric Administration, 2020). It is important to note that when addressing oceanic pollution, no examples or images of animals injured by plastic were shown. While we often see images of seagulls with stomachs full of microplastic when talking about pollution, I thought it was not in the teacher's or student's interests to show that kind media in class, as when Bloom & Holden (2011) encountered similar topics in his course, students had a grim view of environmental issues.

Each pair of lab partners was given a different microplastic mix that contained plastics from three RICs. Students dumped their mixes into solution seven, which had the highest density. Using the same procedure as the first activity, the floating microplastics were transferred to the next solution until either all pieces sank, or they reached solution one. Students could then use their written observations to determine the identity of their microplastics. With water as solution four, students were given the tools to visualize how low density microplastics float at the ocean surface, while denser plastics sink to the ocean floor. After filtering and identifying microplastics, the students were asked to reflect on their own plastic usage and consider how they could change their habits.

Fifth-Grade Curriculum

Roughly halfway through the semester, students completed three laboratory activities that could be easily modified to fit fifth-grade curriculum. All three activities were based on water and plastic pollution. The first activity, a "Water Pollution Clean-up Challenge," created by Dr. Johnson, assigned lab partners (or a group of fifth graders) to clean up a very polluted body of water. The water is polluted with cocoa powder, vinegar, vegetable oil, microplastics, and other kid-friendly "pollutants." Students were presented a list of treatments, as well as the cost and time associated, but are only allowed to choose two treatments. The treatment options are listed in Appendix I with the Prep Day Lab Report. Students recorded a clean-up plan, data collected from the clean-up process, the resulting safety of their water, as well as clean-up plan revisions. The clean-up process resumed with the new plan and data recorded in the same format as the first trial.

The next activity in the sequence was a modified version of the microplastics filtration, but with only three of the seven solutions (Hughes et al., 2001). This modified procedure, also seen in Appendix I, was designed so that the CHEM 101 students could teach it to a fifth-grade class in a shorter time period. The microplastics that were filtered were from the first activity to add a better sense of realism. Students clean up polluted water and then conduct a density test on microplastics they found so the plastic can be properly recycled. At the end of this activity, students were again asked to think about what they could do about plastic usage in their lives.

The third activity in this small series tested what students know about the length of the life cycle of polymers. This activity is an ocean pollution timeline, titled "How long until it's gone" (Science & Math Investigative Learning Experiences [SMILE], n.d.). This interactive timeline activity presents students with objects and images of common pollutants seen along beaches and lakeshores. Most of the pollutants described in the activity were everyday objects that I was able to bring into the laboratory, but items like cigarette butts, dirty diapers, and tangled fishing line were better presented as photographs. Students matched the objects with printed amounts of time to estimate how long it takes for the object to degrade. The times ranged from six weeks to 600 years and "undetermined" (SMILE, n.d.). Students wrote down their choices and the reasoning behind them, as well as ways they thought debris could make its way into our waterways.

In a related activity, students sorted everyday objects into the categories of "Reduce, Reuse, Recycle, and Trash" as a team. They then discussed why, as well as if knowing decomposition times affected their decision at all. Students were also asked to consider plastic properties and effective uses for them. Lastly there was a fun activity that asked students to creatively express how an individual can impact the environment, using poems, drawings, or any other creative medium.

Are Mushrooms the New Styrofoam?

The next activity in the full laboratory sequence for the study, "Are mushrooms the new styrofoam?" took place over multiple experiments, as there were week-long waiting periods. See Appendix J for full instructions. Transitioning from polymers and plastics to their alternatives, students followed modified Ecovative Design procedure to create their own styrofoam alternatives (Grow.bio, n.d.). The first step, done during Experiment 5, was activating the dormant mycelium material. Mycelium is a mushroom's vegetative root, so there are no mushroom spores. Each pair of lab partners got their own bag of mycelium mix and mixed in the ratio of flour and water listed on their bag. Students placed their mushroom mix bags on laboratory benchtops that were out of direct sunlight for a little over a week to let the mycelium mix grow. After a week, the bags were placed in refrigerators to prevent bacterial growth until the students were able to work on it the next week.

When students returned to their bags of mushroom material, it was ready to be packed into their molds to be shaped. Students packed the growth into the molds they brought or what was available in the laboratory. Once students left their growth forms back on the benchtop, the mycelium mix grew in tight formation and eventually grew through all gaps, creating a firm structure. Mycelium growth forms were removed from their molds after one week and placed them on paper towels to dry. At the end, students had their own all-natural “styrofoam.”

What Kind of Biopolymer Do You Want to Make?

The last activity in the laboratory sequence gave students a more in-depth look at polymer plastic alternatives. Modified from “Polymers for the Planet,” this activity has students design the biopolymers asked for in the “company letter” from the beginning of the semester (Teaching Channel and Boeing, 2016). Part 3 of Experiment Six, “What kind of biopolymers do you want to make?” (located in Appendix J) was part of the chemical reaction lab. Lab partners chose what starch, plasticizer, and amount of glue they wanted to use and signed up on the sheet in Appendix K. The potato, corn, and arrowroot starches were chosen from a list in “Polymers for the Planet” curriculum based on cost and availability. The two plasticizers were different ratios of glycerol or glycerin in water (Teaching Channel and Boeing, 2016). Students prepared two biopolymers: one with glue as an additive, and one without. The starting materials were heated up in beakers at 220-330 ºC and stirred continuously until they boiled. Students then poured their two biopolymers into their respective weighing boats. Students took observations and compared their two biopolymers immediately after they were poured and then left them for several weeks to set. I had prepared several samples ahead of time for students to observe, and students observed each other's biopolymers as well.

After the biopolymers had set, students started, "What properties do your biopolymers have?" as part of Experiment Seven and recorded observations of both of their biopolymers. Students then conducted a stretch test, where they measured the lengths of cut strips of polymer and then gently stretched that material alongside a ruler until it broke (Teaching Channel and Boeing, 2016"). The students took observations, recorded the final length, then calculated the percentage that the polymers elongated. There were three trials for each biopolymer, then students calculated the average percent elongation. To encourage students to think about what the results of this test may indicate, students were asked to compare various biopolymers with and without additives and consider what kind of products these biopolymers could make.

Qualitative Data Collection

To ensure a full picture of the students' laboratory experience, five types of data collection were used for this study: classroom observation, pre- and post-polymer laboratories surveys, post-laboratory surveys, lab report data, and focus group interviews. Co-results with multiple types of data collection in this manner is known as method triangulation and provides a comprehensive understanding of study outcomes (Patton, 1999).

Observations

Classroom observations in educational research are important for many purposes, including more accurate detailing of instructional events, studying the learning process in action, and improving knowledge of teaching models (Waxman, 2004). Researchers like Herb Walberg (1995) used observations to identify classroom behaviors that relate to student achievement. In contrast, observations are often used to find instructional strategies that have discriminatory concerns. Observations such as these and many others have effectively improved teacher's curriculum and student interactions. However, observations are not a perfect research tool; researchers may wrongly label student behaviors or emotions (Baker & Lee, 2011). There is arguable bias in choosing which variables to observe, as these decisions may not be clear. Limitations and interferences with this data collection method includes the change in behavior of both students and teachers that know they are being observed (Waxman, 2004).

I intended to use classroom observations to modify laboratory procedures to run better since they are proven to improve teaching outcomes (Waxman, 2004). For this study, I sat in on every class period when one of the polymer units was taught. In order to ensure my presence would not affect data collection, students were aware that course observations were part of my research but did not know that I wrote the laboratories. Throughout the semester, I took notes and looked for student comprehension of material and lab procedure, general responses, and questions. These observations were done to see how the laboratories worked in a classroom setting and to study students' learning process. Observing this and student demeanor during the laboratory also enabled me to see the effect of the course material more than a traditional survey would. Observations were recorded on a password protected laptop for participant confidentiality.

Pre/Post-Course Surveys

Pre-course surveys assess student understanding of curriculum and attitude towards specific topics at the beginning of the semester, which is later compared to post-course surveys at the end of the polymer lab sequence (Sumner & Capano, 2010). This comparison can show the changes in student comprehension and attitudes towards course material. While these surveys provide useful information, there are some minor issues, such as the fact that students who are more effective at self-regulation can provide more accurate survey feedback. Based on this, students who struggle with self-regulation may provide less accurate feedback. Despite this, pre- and post-course surveys are still beneficial, as they can determine how well a student learned and reached course objectives. These are also useful for curriculum development, as the data can be used to evaluate a course's success in meeting its goals (Sumner & Capano, 2010).

Pre- and Post-course surveys were handed out at the beginning of the semester and after the polymer units for this study were complete. This survey can be found in Appendix L. There was a total of four questions that covered student knowledge, beliefs, attitudes, and practices regarding polymers and plastic pollution. The survey had a combination of multiple choice and short answer formatting. Of the 18 students registered in the course, 15 agreed to participate in this part of the study.

Students did not have their "pre" survey available to look at when filling out their post surveys, which is standard, but in our case led to some inconsistencies. For the students whose answers did not match their beliefs or discussions in previous labs and surveys, I did some member checking, where participants are given their results back to check credibility (Birt et al., 2016). I confirmed students' survey answers and allowed them to make edits to their survey if they felt it did not reflect their beliefs. Students initialed any changes they made for transparency's sake. I was unable to talk to all the students whose surveys showed inconsistencies, as two were absent on the day I was able to come into the classroom for member-checking.

Post-Laboratory Surveys

Student surveys for classroom activities are a way to quickly receive detailed feedback on the activity and how students went through it. These surveys can be delivered in a variety of media at various lengths and are an important part of educational research. Student surveys give students a voice to speak about issues with activities, what went well, and how teachers can better assist them (Minero, 2014). One downside is that there are usually issues with student participation, such as short responses with little information, or no responses at all from some students. That said, there are still many substantial responses that make it worth including in qualitative education research.

For this study, post-laboratory surveys (located in Appendix M) were available for students to pick up on the laboratory bench where they turned in the previous week's report. Students were asked to complete these surveys before the end of the class period, but occasionally students took them home to finish. There were four questions regarding student opinion of the lab procedure and topic(s) covered, as well as if they intended to include the material in their future curriculum. On average, 16 out of 18 students participated. The survey questions were the same for every laboratory, with one minor exception halfway through the semester. In the question, "What material in this module about [insert lab topic] was the most significant to you? Explain," I changed the word from "material" to "concept" for clarification. My intention was for students to discuss the topics and background of the laboratories, but many students were recording what physical material appeared to be most important in the laboratory, such as plastics and Bunsen burners.

Lab Reports

Curriculum for the course included laboratory reports for students to fill out during the laboratory each week. As it was already built into the course, this qualitative data collection was well designed by Dr. Johnson and not difficult to collect. To better encourage critical thinking, students were given the next week to complete their reports. These were turned in at the beginning of the next lab and subsequently scanned into pdf format. Giving students a week to complete their reports allowed us to ask more in depth and philosophical questions that take time and thought to answer well. The previously existing CHEM 101 labs were modified to fit the environmental focus and asked a handful of additional or replacement questions that related to the lab activities designed for this course.

Focus Groups

Focus group interviews are an excellent method for gathering qualitative data (Dilshad & Latif, 2013). These interviews are small groups with a moderator, who asks questions to determine general attitudes and perceptions on a given subject. In a typical focus group interview, the group is given a prompt by the moderator and discussion and interaction between different members of the group is encouraged. This can give researchers a greater understanding of the perspectives and underlying rationales of the group participants than they might get from a typical survey (Dilshad & Latif, 2013). Focus groups allow members to incite more responses from each other and build from their comments, creating more data (Patton, 1999). The downside is that these discussions make it difficult to know what individual participants think when there is no input. It is worth noting that according to Dilshad & Latif (2013), focus groups are not useful for the collection of quantitative data or for topics that are difficult for most people to discuss in group settings.

Data Analysis

Once data collection was completed, I began the qualitative analysis process. This entailed looking for trends in the data and developing descriptive codes, also known as inductive analysis (Patton, 1999). The responses for each survey and interview question were grouped based on similarities in phrase and tone. Each grouping was described with a singular term or brief list as a code. Student responses were sorted and grouped repeatedly in order to ensure that the qualitative codes were a good fit for the data. This was repeated for all written and verbal response research data.

Each interview and survey question has its own set of codes, which can be found in the chapter corresponding to the data collection method used (see Chapters 3 through 7). Total code frequency varied, as student responses would frequently have to be split between multiple codes. The major themes considered when developing codes were the two guiding research questions. For numerical and multiple-choice data, simple statistics were used to organize the data into charts. This is used solely for the multiple-choice questions in the pre/post course surveys that can be seen in Chapter 4: Pre/Post-course Survey Data.

Limitations

The sample size, sampling technique, and course used for this study cannot be extrapolated to be assumed as the same for all general chemistry students. The data presented here provides an in-depth look at how polymer pollution focused general chemistry education affected student perceptions about the topic in this specific course section. My intention for this study was not for this data to be used to represent all students, but for other educators to see and consider how their own students would approach the laboratories presented.

Chapter 3: Observational Data

Observations were conducted during the laboratories written for this study. Notes were recorded on a password protected laptop in order to maintain confidentiality. Students were aware that I was observing and taking notes for my thesis research but were unaware that I had written the laboratories. Accordingly, the students' views about the laboratories remained unbiased. General observations were also taken from Dr. Johnson and the teaching assistant, Mary Bautista.

Observations were used in this study to see how the laboratories ran in a classroom setting. They were also used to examine and analyze the students' understanding of the material being taught, and their reactions during the physical experimental processes. While post-laboratory surveys included questions and information about laboratory activities, being present as an observer provided additional context and allowed me to observe details students did not bring up during the post-laboratory reviews and subsequent focus group interviews. My observations were not as formal as surveys and interviews but proved a helpful tool for assessing laboratory performance. These observations are presented under the title of each respective laboratory, in the order the labs were run.

Why Do We Need a Better Plastic?

The first experiment was a read and response section, so there were not any observations from this laboratory.

Why Do Plastic Containers Have Those Different Numbers Stamped on Them?

Students provided a great deal of immediate feedback regarding issues and questions that came up during this lab. The activity where students used solutions and density data to determine the identity of microplastics was very chaotic. Specifically, the difficulties with the microplastic filtration resulted in multiple students, the teaching assistant Mary, Dr. Johnson, and myself to cross the room back and forth periodically to attempt to identify problems and find ways to fix them. While I was able to remove plastics from the solutions with a spoon without difficulty when I practiced the lab, I did not realize that switching to larger beakers for implementation with the students would cause microplastic removal via spoon to be nearly impossible. Filtration of the microplastics improved when metal and ceramic screens placed over a beaker were used instead. Students specifically mentioned this in my observations:

- "This is difficult, but we'll live"
- "Kind of aggravating, but it's weird"

This experiment was supposed to be somewhat frustrating, but it became a point of stress for students. One student even did a round of slow clapping when their last pieces of microplastics sank into a beaker of solution. Based on the problem-not having enough stations to do the microplastic filtration, the rush to finish on time, and some issues with rinsing the plastic pieces between solutions-it was clear that the source of student frustration was not at the course material but with my preparation for the laboratory. In preparing, I had forgotten to consider some issues that can arise when running a laboratory on a larger scale. Students adapted, though, working together very well as issues arose. Different pairs of lab partners even helped others finish the microplastic activity in a timely manner.

Despite the frustration and problems, students still had great questions and observations. Students observed that some microplastics did not sink or float, which led to further investigation by the students. After talking it out with their lab partner and asking me some questions about microplastics, students hypothesized that it was due to a lack of vigorous stirring or residual paper labeling on the microplastics that absorbed water. Comments and observations, I found interesting are as follows:

- “So are these microplastics from the paper [from the week’s reading material], or do they get even smaller”
- “We had ones sink that we thought would float, so it was less about the air bubbles [their initial hypothesis]. We think it had paper and it absorbed, so it’s not [air bubbles].”

Are Mushrooms the New Styrofoam?

The mycelium mushroom mix laboratory activity was much easier for students to complete than the other laboratories, as it mainly consisted of mixing material, and then later pressing it into shaping containers. The only physical issues encountered was that mold grew on some of the mushroom mix materials between class sessions. Some students were able to remove these moldy sections, while others had to throw it away and share mycelium mushroom mix with fellow students. These mushrooms were contaminated due to students failing to follow sanitation procedures, so these students also learned the importance of avoiding contamination.

Introducing an environmentally friendly styrofoam alternative to the students was interesting, as they all had different reactions to the concept. Some were unsurprised, or disinterested, there was not a distinct difference between the reactions of these students. Others thought the idea was very cool and asked various questions throughout the activity. Many were surprised by the concept that a small plant-based material, like the mulch in the experiment, could grow and become something as sturdy as standard styrofoam.

- “I wonder if you could plant in it, or if it’s wet the mushrooms will get squishy.”

Students took an experimental approach with the molding of the mushroom mix, trying out different packing methods to see what would happen. One result was a beaker's permanent mushroom "styrofoam" cover. Many students brought items from home to use as molds, making types of flowerpots or using other creative options. One group built a "spaceship", and another brought cookie cutters in the shape of the state of Michigan, shown in Figure 3.

Figure 3

Mycelium Growth

Note. Mycelium mushroom styrofoam alternative made by a student. Cookie cutter was placed in the mold so the mycelium in the cutter was an entirely different growth.

What Kind of Biopolymers Do You Want to Make?

The biopolymer laboratory experiments both had a focus on student observation, so students interacted with several biopolymers in a couple of different ways. This experiment was more fun for students, as they got to choose what kind of biopolymer they made, how much glue to put in, and what combination of food coloring to use for a fun look. I had made examples of biopolymers ahead of time (see Figure 4), so I was able to observe students interacting with the materials before they made their own.

Figure 4

Biopolymer Samples

Note. A collection of different biopolymer samples set aside to harden.

It was interesting to see the thought process and methods students used when observing the variety of biopolymer samples. Some students poked a couple of samples and then went on to make their own, while others had fun feeling the difference between samples and finding as many “squishy” or “jello-like” polymers as possible. A handful of students were very methodical about how they used the biopolymer samples to choose their ingredients. They tested each one and noted which properties they liked and what material was associated with each. They examined the samples, determining how different amounts of the glue additive impact “springiness” to get the desired consistency. Once students started making their biopolymers, the biggest issue was the timing. I had likely not factored the proper amount of time for the hot plates to heat up to the temperature needed when timing my trials.

Once the biopolymers had set for a couple of weeks, students returned to find out how they turned out. Some biopolymers did not retain their bright colors. Others shrank in size and became hard. To our surprise, some biopolymers never firmed up at all. Part of the laboratory was conducting a stretch test, so students with liquid polymers used samples that had hardened from the first week. When comparing their biopolymers with and without a glue additive, they were surprised to find that the glue biopolymers were much harder and more difficult to stretch. I discussed this with some students, and we noted that while glue is very pliable, it becomes incredibly hard when dried.

I was particularly struck by one set of lab partners’ attitude and thought process towards their biopolymer’s liquid state and have included a summarized transcript below using pseudonyms:

Charlie (C): “We could put it in a container?”

Salem: “I don’t know if it would hold its shape. These would make *excellent* gel packs.”

C: "Maybe, we don't know how it would react with heat or cold. Well it's thinner, and looking back to [Why do plastic containers have those different numbers stamped on them?] lab, the thinner plastics had different uses than the thicker plastics. So could it be used for those things?"

C: (later) "We were thinking that because this is so liquidity that it could be a synthetic oil or lubricant. I really want to know how it reacts with heat."

This caught my attention when reviewing my observation notes because of their positive approach to lab errors and most importantly, to their reference to polymer lab information from several weeks prior. They took their knowledge of polymers' multiple applications and applied it to the biopolymer they created.

Conducting observations gave me better insight into how I can improve laboratory preparation and procedures for the experiments in this study. Overall, I will allow more preparation time before the laboratory to ensure everything works and is accounted for. All experiments will be run multiple times in advance in order to check for unexpected errors.

Specifically, there are many ways to improve the "Why do Plastics Containers Have Those Different Numbers Stamped on Them?" laboratory activities. In order to address the biggest concern of time management, multiple stations of this activity will be prepared in the future and microplastic transfer will be conducted with mesh tea steepers. The scale of the filtration will be reduced to smaller 250 mL beakers, as 600 mL was too much. The microplastics will be prepped more thoroughly by checking all plastics for paper residue that could interfere with plastic flotation.

The "Are Mushrooms the New Styrofoam?" laboratory had a few issues that could be fixed quickly. The importance of equipment sanitization needed to be demonstrated and emphasized further during instruction to reduce the amount of blue mold growth in the mycelium. In addition, a smaller amount of mycelium mushroom mix material will be purchased in the future to reduce the amount of unused mycelium left over.

To improve the “What Kind of Biopolymer Do You Want to Make?” laboratory, I will begin the laboratory by preheating the hot plates next time. The fact that each biopolymer had different properties led to issues while making and testing them. I will also test every combination of biopolymer ingredients to make sure they can be heated and blended within the lab period, as well as solidify into a testable polymer.

Chapter 4: Pre/Post-Course Survey Data

Pre- and post-course surveys were handed out at the beginning of the semester and at the end of the semester after the laboratory units for this study were complete. This survey can be found in Appendix L. The survey asked two short answer questions and two questions that required both short answer and multiple-choice selection formatting. Fifteen of the 18 total students in the class participated in the survey.

This survey was designed to assess how students knew, interacted with, and felt about polymers and plastic pollution at the beginning and end of the course. In addition, it was written to accurately assess if their attitudes or behaviors had changed by the end of the study. The data from these responses was used to help determine the effectiveness of the written curriculum, when accompanied with other survey data. There was one more post-course response than the original pre-course surveys because one student was absent on the day the pre-course surveys were filled out, as shown in Tables 1 and 2. The number of responses to specific survey questions varied, as some students did not complete their surveys before handing them in, as shown in Table 1. Student survey answers were coded into different categories, with some answers fitting more than one code.

Table 1

Pre- & Post-Course Survey Response Data

Question	Number of responses			
	Students		Total coded	
	Pre	Post	Pre	Post
Describe in your own terms what a polymer is.	12	13	17	18
What polymers do you use in day-to-day life?	11	14	29	14
How often do you recycle plastic containers/bottles? (Likert scale)	15	15	15	15
How often do you recycle paper? (Likert scale)	15	15	15	15
How often do you recycle aluminum cans? (Likert scale)	15	15	15	15
How often do you recycle plastic, paper, and aluminum?	12	11	22	23
Why do you recycle?	8	6	8	6
To what extent do you believe plastic pollution to be a problem? (Likert scale)	15	14	15	14
To what extent do you believe plastic pollution to be a problem?	5	12	5	12
Why do you believe plastic pollution is a problem?	14	13	32	25

Note. Pre- & post-course data of student responses and number of codes the responses were sorted into.

Table 2

Frequency and Response Percentages for Pre-/Post-Course Survey Question 1: Describe in Your Own Terms What A Polymer Is

Code	Frequency		Percent response		Pre- to post-course change	
	Pre- *N*=13	Post- *N*=16	Pre-	Post-	Frequency change	Percent change
Plastic	4	4	31%	25%	0	19% decrease
Synthetic, Makes Up Plastic	7	6	54%	38%	-1	30% decrease
Molecule/Comp-ound/Monomer	2	2	15%	12%	0	20% decrease
Plastic Replacement	0	4	0.0%	25%	+4	N/A

Note. The *N* values differ due to one student dropping the course and other students skipping the question.

Question 1 asked students to describe polymers in their own terms. Student responses fit into four code categories, shown in Table 1. I was surprised that two students were familiar with basic chemistry terminology relating to polymers, as it is not included in NGSS standards. These responses were recorded as *molecule/compound/monomer,* as shown in Table 1. The frequency of this response did not change at the end of the semester but has the indication of a lower percentage due to increasingly varied responses. The codes may be mentioned the same number of times in both the pre- and post-course surveys, but their respective response percentage may change due to students mentioning more or less topics in their survey responses.

Three codes shared the theme of plastic, together making up more than 50% of student descriptions, indicating that most students equated polymers to plastic in some form. Nearly half of students had either the same or similar answers at the end of the semester. Looking at student descriptions of polymers at the end of the semester, I believe response percentages decreased for a couple of reasons. There were more thorough responses from students who originally either did not answer or were unsure. The most surprising data was the code that was added after the post-surveys, reflecting student belief that polymers were not the origin of plastic, but a replacement for it. Student responses mentioning plastic replacements totaled to over 20%. This could be an indication that I did not clearly classify both plastics and plastic replacements as polymers and is worth investigating. Although there was still a fair amount of deviation about the details, more students had some idea of what a polymer was by the end of the course than at the beginning.

The second pre/post-survey question elaborated on the first, asking students to identify polymers they encounter daily. Student responses were descriptive, so they were split further into about 30 separate phrases that were sorted in nine different codes. These codes are organized in Table 3. Similar to the first question, student responses focused largely on plastic. I observed that these references to plastic varied, and divided codes further into subcategories. These subcategories specified what kind of plastic items students mentioned. A second subcategory code was created because responses to the code, "Plastic food/drink containers," referenced plastic water bottles several times. These frequencies and their subsequent percentages of responses are reported in Table 3.

As expected, there were a few responses that showed no indication of polymer knowledge at the beginning of the course, but this number decreased at the end of the semester.

Looking at the percent differences from the beginning to end of the study, more students recognized that there are many polymers used in day-to-day life, after doing these activities. There was also a significant increase in the number of students whose responses included several references to plastic polymers that contained food and drink, which was also emphasized throughout the semester. I was surprised by the need to include a code for recycling, as I did not expect students to connect recycling to polymers by simply asking them to list polymers they knew. After a lot of emphasis on recycling throughout the study, students were mentioning recycling before the recycling portion of the post course survey. The code for other polymers was also interesting to evaluate, as these answers were not solely focused on plastic. Students referenced polymers such as nylon and rubber, indicating the possibility of a more in-depth understanding of polymers.

Table 3

Frequency and Response Percentages for Pre/Post-Course Survey Question 2

Code	Frequency		Response percentage		Pre- to post- change	
	Pre- *N*=25	Post- *N*=29	Pre-	Post-	Frequency change	Percentage change
Plastic	4	2	16%	7%	-2	56% decrease
Plastic school supplies	5	2	20%	7%	-3	65% decrease
Plastic food/drink containers	3	7	12%	24%	+4	100% increase
Other Plastic items	5	5	20%	17%	0	15% decrease
Water bottles	3	4	12%	14%	+1	17% increase
Other Polymers	4	4	16%	14%	0	13% decrease
Mentions "everywhere" or "so many"	1	3	4%	10%	+2	150% increase
Recycling	0	2	0.0%	7%	+2	N/A

Note. Pre/Post-Course Survey Question 2 is "What Polymers Do You Use in Day-to-Day Life?"

The last two questions in the pre/post-course survey were a combination of multiple-choice and short answer. Multiple-choice answers are presented as pie charts so response percentages and frequency can be presented clearly.

Figure 5

Likert Scale for Question 3 in Pre/Post Course Surveys.

Almost never	About 25% of the time	About 50% of the time	About 75% of the time	Nearly always

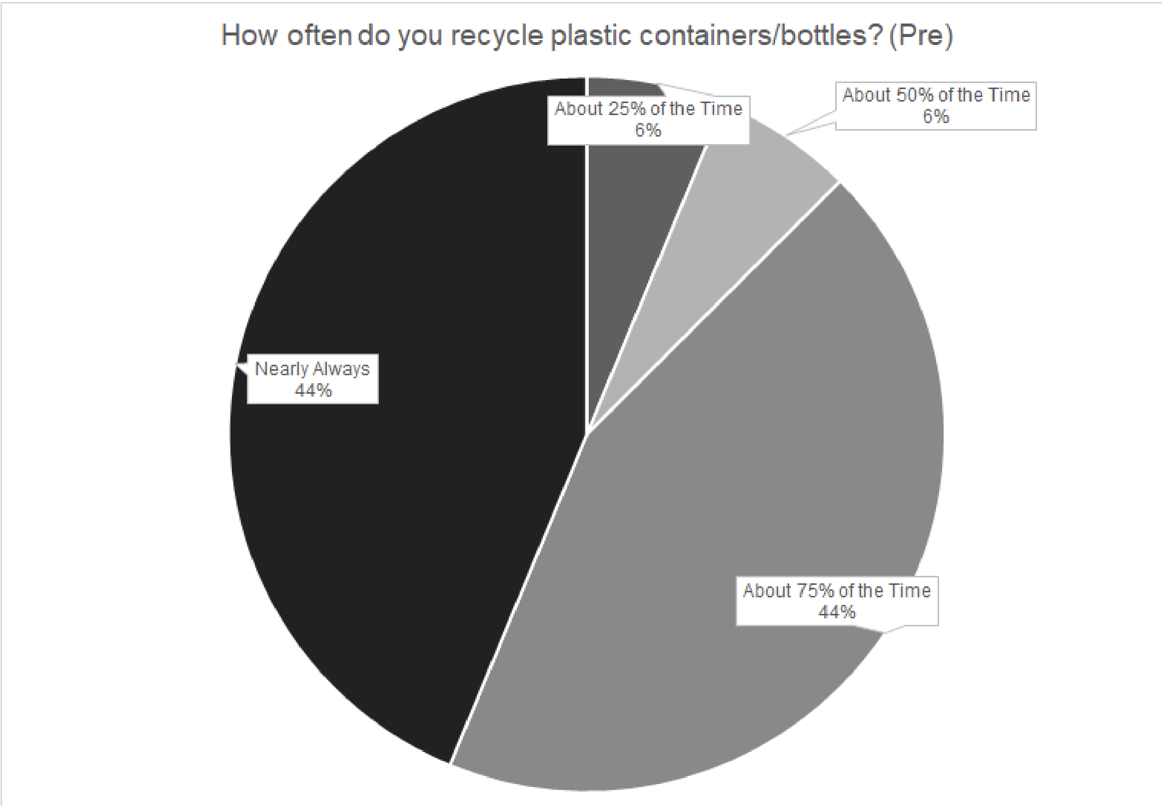
Note. Likert scale description chosen to ensure comparable data.

Question 3 asked students how often they recycled plastic, paper, and aluminum and their reasoning for it. The choices listed are in Figure 5, seen above, using a Likert scale. This Likert scale was chosen for clarity, as it is more clear than traditional options such as "somewhat agree." The intention was for students to think about what they do every time they use plastic and consider their recycling percentage. A Likert scale was considered that listed a specific number of times recycled in a week but was dismissed due to too many variables that a student could misread. After looking through end of semester data, it seemed that some students recycled multiple times a day while others only recycled once a week, but with different amounts of materials. The percentage scale used in this study is a better fit, as it was fairer and clearer for student use. The *N* values for all the Likert scale percentages is 15, based on 15 categorized responses, which is also the number of student responses.

At the beginning of the semester, most students recycled plastic containers regularly, 44% of students said they recycle 75% of the time they use them, and another 44% said they nearly always recycle plastic containers and bottles (see Figure 6).

Figure 6

Pre-Course Survey Answers to the Question "How Often Do You Recycle Plastic Containers/Bottles?"



Note. Student responses about recycling frequency on a Likert scale.

At the end of the semester, that number grew to 56% of students saying they nearly always recycle these plastics, shown in Figure 7. When comparing the charts, it appears that the increase is due to 12% of students that recycled 75% of the time now nearly always recycle plastic bottles.

Figure 7

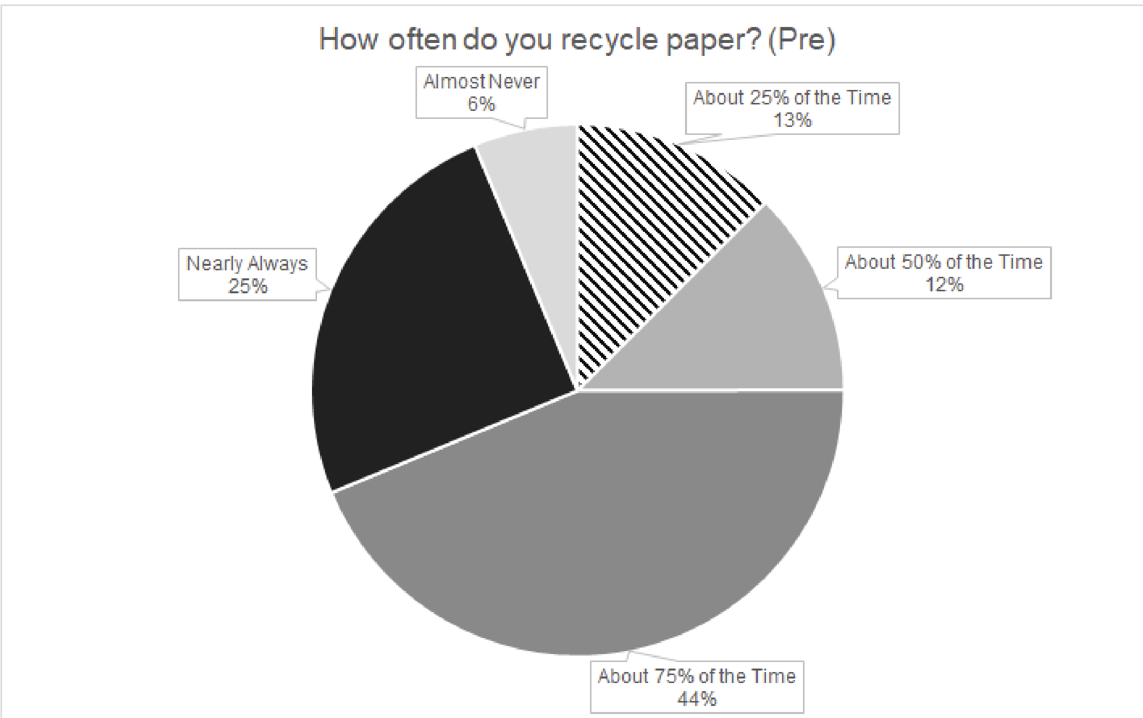
Post-Course Survey Answers to the Question "How Often Do You Recycle Plastic Containers/Bottles?"

Note. Student responses about recycling frequency on a Likert scale.

The frequency of students' initial paper recycling was not as much as their plastic recycling (see Figure 8), but most students still recycle paper very often. A quarter of students nearly always recycled paper and an additional 44% recycled paper 75% of the time. There were students who were not avid paper recyclers, as 6% almost never recycled it and 13% only recycled paper a quarter of the time. At the end of the semester, there were no students that almost never recycled paper (see Figure 9). The percentage of students who recycled paper a quarter of the time they used it increased by roughly the same number of students who rarely recycled initially. The number of students who recycled paper 75% of the time decreased by 10% in the post surveys, and the amount who always recycled increased by nearly the same amount. This likely indicated that, just like the plastic recycling, some of the students who recycled 75% of the time now nearly always recycle paper.

Figure 8

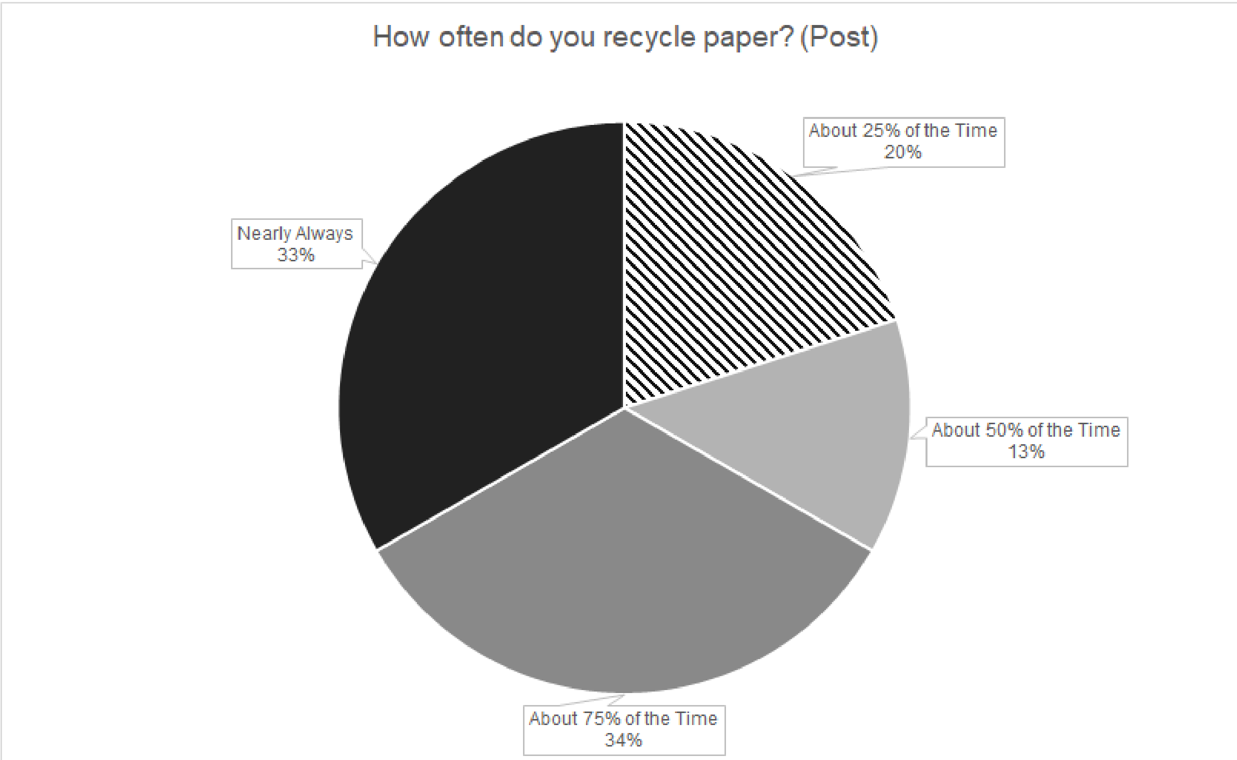
Pre-Course Survey Answers to the Question "How Often Do You Recycle Paper?"



Note. Student responses about recycling frequency on a Likert scale.

Figure 9

Post-Course Survey Answers to the Question "How Often Do You Recycle Paper?"

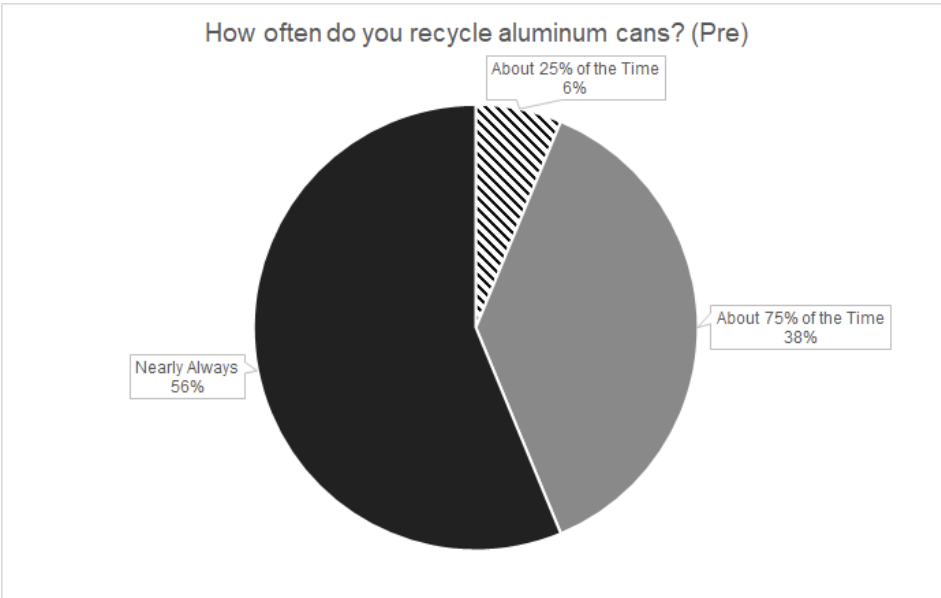


Note. Student responses about recycling frequency on a Likert scale.

Aluminum is recycled the most out of the three materials we asked students about. Initially, 56% of students nearly always recycled their aluminum cans and 38% recycled them 75% of the time (see Figure 10). Comparing this to the post course survey data, the percentage of students that nearly always recycle the aluminum increased by the same amount that the "About 75% of the time" percentage decreased (see figure 11). This has the same indication as the two previous materials: About 17% of students who recycled aluminum cans about 75% of the time indicated that they now nearly always recycle them. One student, the 6% in the pre-survey, only recycles aluminum cans a quarter of the time they used them and continues to do so.

Figure 10

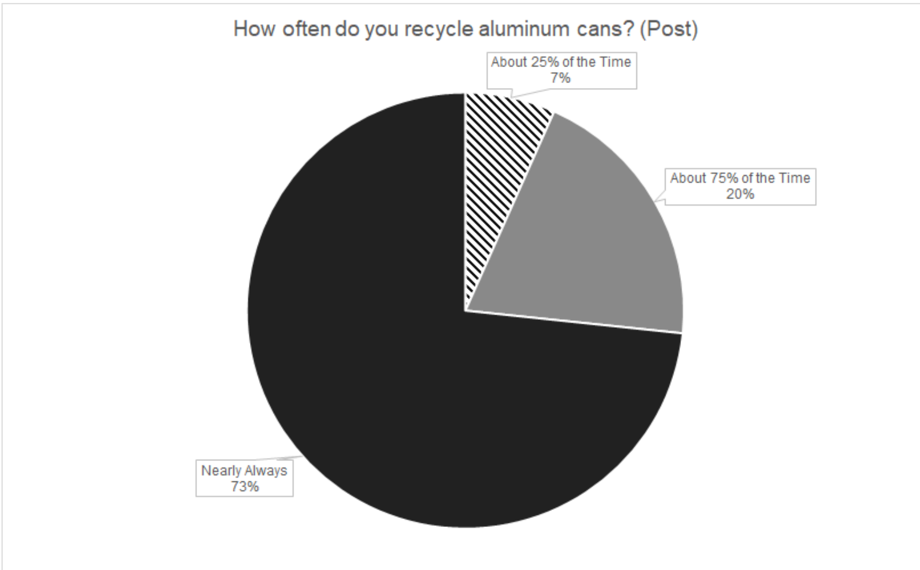
Pre-Course Survey Student Answers to the Question "How Often Do You Recycle Aluminum Cans?"



Note. Student responses about recycling frequency on a Likert scale.

Figure 11

Post-Course Survey Student Answers to the Question "How Often Do You Recycle Aluminum Cans?"



Note. Student responses about recycling frequency on a Likert scale.

The end of Question 3 had space for students to explain why they recycle as often as they stated. These responses were coded qualitatively into two sets of code. One code for how often and where students recycled, then one code for why, shown in Table 4. The *N* values indicate the number of coded responses, as some survey responses were separated into multiple code categories. The *N* value is not the same for the pre- and post-course responses because the number of coded responses from survey answers changed.

Table 4

Frequency and Response Percentages for Pre/Post-Course Survey Question 3: How Often Do You Recycle Plastic, Paper, and Aluminum and Why?

How often do you recycle plastic, paper, and aluminum?	Frequency		Response percentage		Pre- to post- change	
	Pre- *N*=22	Post- *N*=23	Pre-survey	Post-survey	Frequency change pre- to post-	Percent change
Recycle when/where available (not always available)	9	6	40.9%	26.1%	-3	36.2% decrease
Recycle at home	3	3	13.6%	13.0%	0	4.6% decrease
Cannot recycle at home, too costly	2	2	9.1%	8.7%	0	4.4% decrease
Recycle at work	1	1	4.5%	4.3%	0	4.4% decrease
Cannot recycle at work	1	1	4.5%	4.3%	0	4.4% decrease

Table 4 continued

How often do you recycle plastic, paper, and aluminum?	Frequency		Response percentage		Pre- to post- change	
	Pre- *N*=22	Post- *N*=23	Pre-survey	Post-survey	Frequency change pre- to post-	Percent change
Related comments/specific issues	3	5	13.6%	21.7%	+2	59.6% increase
Efforts take to recycle, even when it is not convenient	0	3	0.0%	13.0%	+3	N/A
Why do you recycle?	N = 8	N = 6				
Aluminum, 10 cent deposit	5	2	62.5%	33.3%	-3	46.7% decrease
Because I have always recycled	2	2	25.0%	33.3%	0	24.9% increase
Environmental Protection	1	2	12.5%	33.3%	+1	62.5% increase

Note. Responses for both "How often do you recycle plastic/paper/aluminum?" and the corresponding "Why?"

About 41% of students said they recycle when they can at the beginning of the course, with various comments indicating the times when they could and could not. These explanations are organized into other codes about home and work, with a nearly even split between student's ability to recycle at these locations. Three students can recycle at home, while two cannot. One student recycles at work, while another cited that they cannot be due to HIPAA regulations against recycling patient paperwork that protects private health information. A few students mentioned that they cannot recycle while "on the go." A code category was created that included additional details about student recycling habits. Some mentioned that if there is not a recycling bin, they will throw things away, or mention the difficulty of finding a recycling bin when not at home. Most of these responses stayed the same except for a decrease in the number of comments related to recycling whenever possible and an increase in added details. One student told me that they have been recycling less due to exam fatigue, so that is also a possible factor in the percentage decrease of students recycling when available. A new code was created for the post surveys that indicates positive changes in student attitudes towards recycling despite fatigue. Three students said that they make a point to recycle even if it is not convenient:

- "...if I have a lot to throw away, I will wait until I see a recycling bin."
- "I make it my daily duty to keep my carbon footprint as small as it possibly can be."
- "I've been trying my best to drive it into town to the drop-off location."

A few students also gave reasoning for their recycling habits, all of which fit into three categories: aluminum deposits, to protect the environment, and because they are simply always. Response levels for these questions in this survey are low due to students skipping over questions as they completed surveys. It is worth mentioning that all the data on recycling habits is self-reported, so there is some possibility that participant responses were affected by perceived social pressure.

Question 4 asked students how much they thought plastic pollution was a problem and why they felt that way. A Likert scale was also used for this question because opinions about this topic vary greatly and I wanted to ensure I had a clear comparison. The options for students' thoughts on plastic pollution are on the scale in Figure 12.

Figure 12

Likert Scale for Question 4 of Pre/Post- Course Surveys.

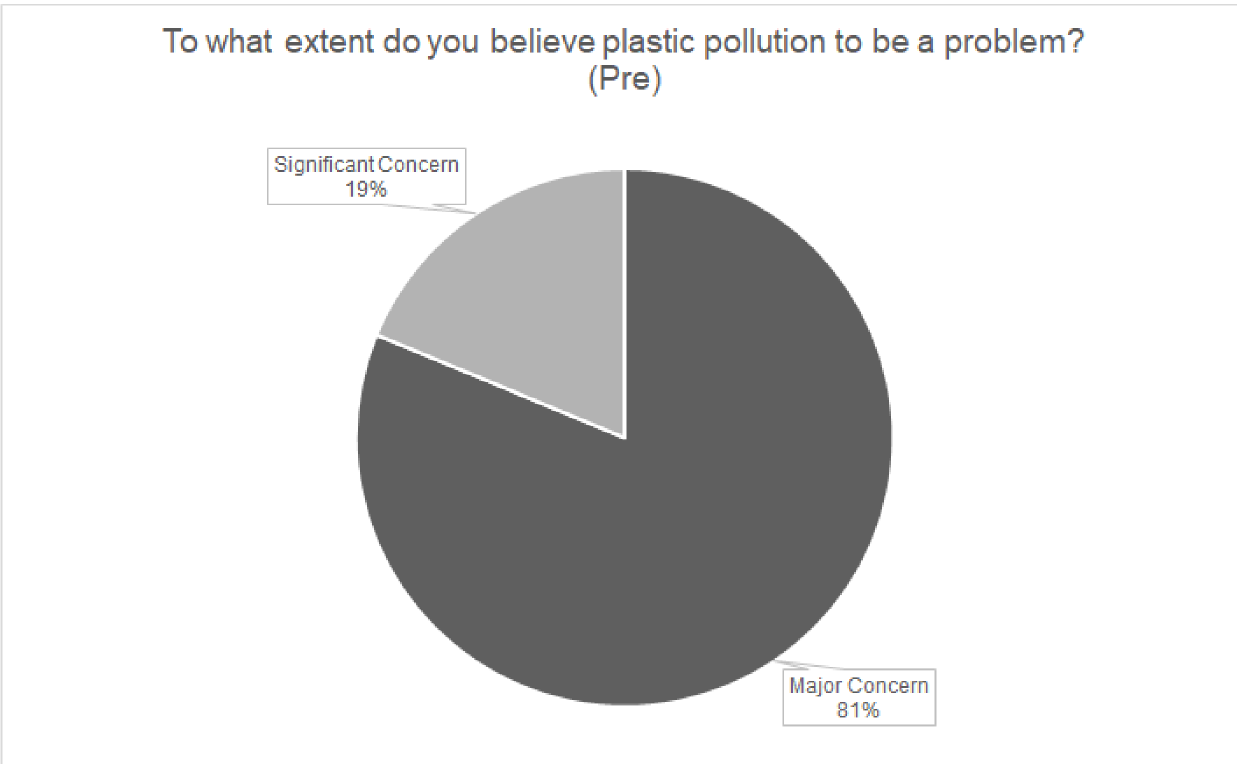
Plastic pollution is not a major problem.	Plastic pollution is an issue but is not a major environmental concern.	Plastic pollution is a significant environmental concern.	Plastic pollution is a major environmental concern and requires immediate intervention.

Note. Student choices for pollution concerns.

These options were chosen to best fit the wide scope of opinions into four broader categories. I decided on this level of detail for the Likert scale because I felt a more detailed Likert scale could be too specific to quickly relate to, and one that was vaguer might confuse students.

Figure 13

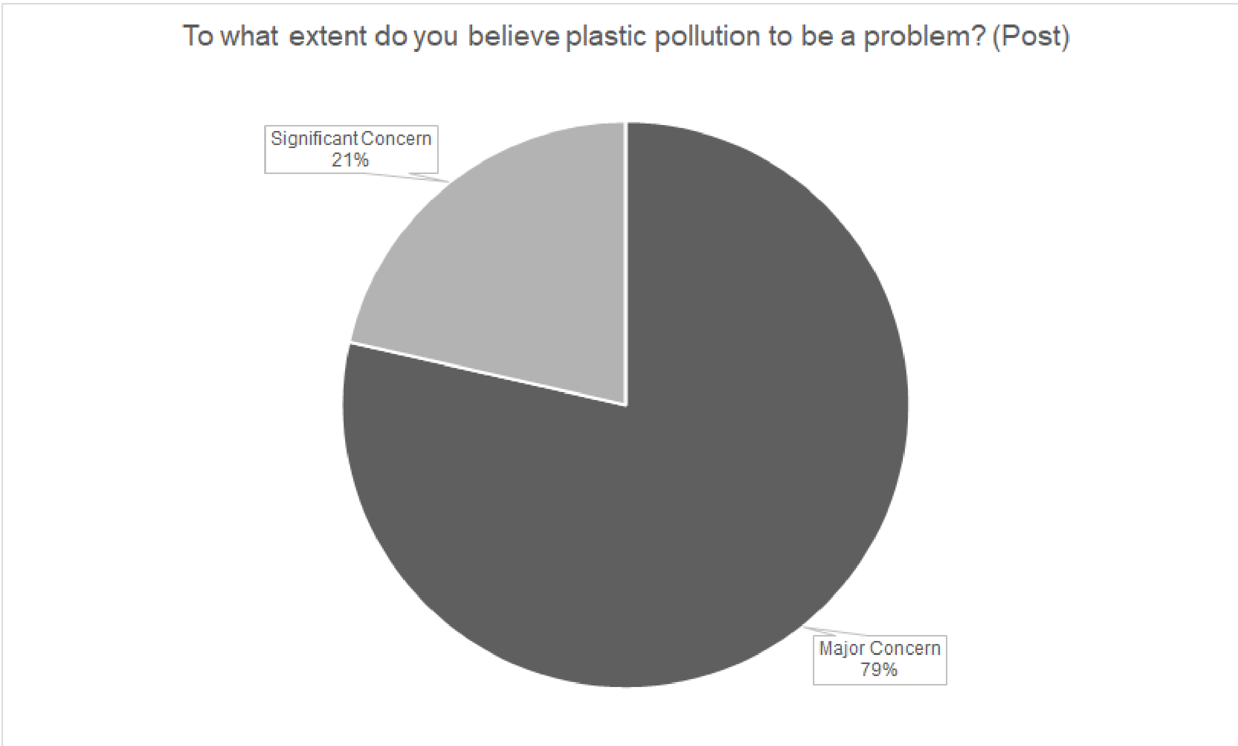
Pre-Course Survey Student Answers to the Question "To What Extent Do You Believe Plastic Pollution to Be a Problem?"



Note. Student responses about pollution concerns on a Likert scale.

Figure 14

Student Post-Course Survey Responses to the Question "To What Extent Do You Believe Plastic Pollution to Be a Problem?"



Note. Student responses about pollution concerns on a Likert scale.

All the students in the course believed plastic pollution is concerning, with 100% of students said that they believed plastic pollution was significant or a major environmental concern (see Figure 13).

Due to the surprising fact that 80% of the students already believed plastic pollution was a major problem at the beginning of the curriculum, it was difficult to determine how much more strongly students felt about this issue at the curriculum's conclusion with the survey questions as worded. Had I used a more specific Likert scale, I would be able to evaluate their feelings on this issue more thoroughly. I was pleased that such a high majority of them already considered the issue major. The more telling piece of data is what percentage of the students believe that immediate action should be taken (see Figure 14). Student responses as to why they believe plastic pollution to be a problem had two main categories, the extent of the pollution and reasoning why, which were made into separate codes. For the most part, the codes about the extent of pollution reiterated the Likert scale options, with two exceptions. One student said that the extent of plastic pollution is unavoidable, although they did not say so initially. Similarly, three students said plastic pollution was not an immediate concern even though no one had said so originally. This differs from the Likert options students chose, which could be the result of a couple different options. I think ecophobia could have played a role here, although the class material was written to reduce the likelihood of ecophobia. Students become overwhelmed by the vast size of a problem and become desensitized to it, deciding that their role in fixing a problem like plastic pollution is too small to be important or worth doing.

Looking at the written responses about plastic pollution beliefs, The *N* values in Table 4 indicate the number of categorized responses, as some survey responses were separated into multiple code categories. The *N* value differs between questions because the number of categorized responses from survey answers changed. Table 5 shows a percent decrease in half of code categories discussing why plastic pollution is a problem because the number of responses decreased. Three codes had an increased percentage that could be correlated to the curriculum in this study. While there was only an increase by one or two students for these codes, it is still worth mentioning. This increase was seen for the concern for human, animals, environmental harm, and mentions of politics or other possible influencers. None of these pre/post changes are significant enough to conclude that students learned this from the polymer curriculum, but they indicate that students are aware of the extensiveness and concerns regarding plastic pollution.

Table 5
Frequency and Response Percentages for Pre/Post-Course Survey Question 4

To what extent do you believe plastic pollution to be a problem?	Frequency *N*=5	Frequency *N*=12	Percentage response pre-survey	Percentage response post-survey	Frequency change pre- to post-	Percentage change
Immediate action. Huge Concern	5	8	100.0%	66.7%	+3	49.9% decrease
Not an immediate concern	0	3	0.0%	25.0%	+3	N/A
Unavoidable	0	1	0.0%	8.3%	+1	N/A
Why do you believe plastic pollution is a problem?	Frequency *N*=32	Frequency *N*=25				
Plastics do not biodegrade easily	6	1	18.8%	4.0%	-5	18.6% decrease
Will only worsen over time (disaster)	4	3	12.5%	12.0%	-1	4.0% decrease
Pollution on land and sea	9	6	28.0%	24.0%	-3	14.3% decrease
Bad for the environment	8	7	25.0%	28.0%	-1	10.7% increase
Harms/Kills animals, people	5	6	15.6%	24.0%	+1	36.3% increase
Science (nonspecific) or government related answer	0	2	0.0%	8.0%	+2	N/A

Note. Pre/Post-Course Survey Question 4 is "To What Extent Do You Believe Plastic Pollution Is a Problem? Why?"

Chapter 5: Post Laboratory Survey Data

Post laboratory surveys were available to students at the end of each laboratory activity written for this study. The surveys were completed before students left class, but students would sometimes take them home and return them the next week with their lab reports. Around 16 out of 18 students participated on average. All surveys were identical, asking the same four questions. There was a minor wording change to the question "What material in this module about [insert lab topic] was the most significant to you? Explain." I replaced "material" with "concept" because I was getting several literal answers stating that lab equipment was the most important when I intended to refer to the curriculum.

This survey was written and incorporated into the study to find out how the students felt about the laboratory experiments while the experiments were fresh in their minds. Course evaluation surveys given at the end of the semester often run into the problem that students cannot remember specific details. I can vouch for this personally, as I can rarely think of good feedback for course material after a few months. Giving students surveys immediately at the end of the laboratory appeared to be the most effective way to get quality student feedback. Students were asked to list positives and negatives, identify what stuck out to them, and if they would choose to include this material in their future curriculum. The laboratory activities that included post laboratory surveys were "Why do we need a better plastic?" "Why do containers have those different numbers stamped on them?" "Are mushrooms the new styrofoam?" and "What kind of biopolymers do you want to make?" The results of the surveys are presented under the name of their respective laboratory.

Why Do We Need A Better Plastic?

This activity was primarily an introduction to the topic of plastic pollution with a read and respond activity, so it did not elicit many strong student opinions. Responses about what went well in the lab were sorted into six codes (see Tables 6 and 7). Fourteen students responded, but one student skipped a question. These student responses were coded into different categories, some with multiple codes for a single response. The total number of coded responses is the N value to calculate percentages.

Table 6

Student Responses and Code Categories For "Why Do We Need a Better Plastic" Post-Lab Survey

Question	Number responses	
	Student	Coded
Name and Explain at Least Two Things That Went Well in Today's Laboratory.	14	25
Name and Explain at Least Two Things in the Experiment Today That Can be Improved to Create a Better Experience.	13	19
What Material was the Most Significant?	14	26
How do You Foresee Using Material from This Unit in Your Future Classroom? If You do not Foresee Using the Material, Explain Why.	14	24

Note. Student responses are sorted into codes, with one response fitting multiple codes, leading to a larger number of coded responses.

Table 7

Frequency and Response Percentages for Post Laboratory Survey "Why Do We Need a Better Plastic?" Lab Question 1

Code	Frequency $N = 25$	Percentage response
Different section of the lab/not applicable	3	12%
Clear and/or ease of activity	4	16%
Procedure/activity went well/was liked	6	24%
Describing why plastics are bad for the environment New plastics needed	3	12%
Multiple sources at multiple reading levels	3	12%
Learned about plastics	6	24%

Note. Lab Question 1 is "Name and Explain at Least Two Things That Went Well in Today's Laboratory."

About 40% of responses about successes in the activity were general comments about how they liked the activity and that the procedure went well (see Table 7). More detailed comments from students were sorted into subcategories that addressed plastic education, plastic pollution education, and the different reading levels of the assigned articles. The two most common critiques of the activity were that the lab should have been more interactive and that providing additional resources (some students specifically requested videos) would have improved the experience (see Table 8).

Table 8

Frequency and Response Percentages for Post-Laboratory Survey "Why Do We Need a Better Plastic?" Lab Question 2

Code	Frequency *N* = 19	Percentage response
Different section of the lab (not applicable)	3	16%
Should be more interactive	6	31%
Provide additional resources	5	26%
Suggestions for a more interactive lab	2	11%
Specifically requested videos	3	16%

Note. Lab Question 2 is "Name and Explain at Least Two Things in the Experiment Today That Can be Improved to Create a Better Experience."

The third question asked students what material was the most significant to them, and a large amount of student responses, around 23%, discussed the need to reduce, reuse, and recycle plastics. These were further sorted into codes that focused on ways to fix plastic problems and ocean plastics, as seen in Table 9. Around 30% of responses mentioned that they learned something new, and an additional 5% cited the articles as the material most significant to them (see Table 9). A survey misinterpretation was discovered here, as some students listed physical objects instead of concepts. I did not immediately change the survey, as I thought it could have been attributed to the fact that it was the first lab in the study or a lack of thorough explanation on my part.

Table 9

Frequency and Response Percentages for Post-Laboratory Survey "Why Do We Need a Better Plastic?" Lab Question 3

Code	Frequency *N* = 26	Percentage response
Different section of lab/N.A.	2	7%
The articles	5	19%
Learned something new	7	30%
Need to reduce/reuse/recycle plastic	6	23%
Ocean plastic	2	7%
Ways to fix the issue	2	7%
Microplastics	2	7%

Note. Lab Question 3 is "What Material was the Most Significant?"

When students were asked if they would teach material from this activity in their future classroom, only one student responded no. A large number of responses talked about the importance of environmental education. It is also worth noting that a quarter of these responses specifically mentioned that they would teach about the negative effects of plastic pollution (see Table 10).

Table 10

Frequency and Response Percentage for Post-Laboratory Survey "Why Do We Need a Better Plastic?" Lab Question 4

Code	Frequency *N* = 24	Percentage response
Different section of the lab (not applicable)	3	12%
Will not use	1	4%
Teach using articles and/or letter	4	17%
Teach environmental education	3	13%
Use additional accompanying activities/projects when teaching this	2	8%
Teach about plastic harming the environment	6	25%
Teach about plastics	5	21%

Note. Lab Question 4 is "How Do You Foresee Using Material from This Unit in Your Future Classroom? If You Do Not Foresee Using the Material, Explain Why."

Why Do Plastic Containers Have Those Different Numbers Stamped on Them?

This laboratory involved three activities of significant length, and as a result, the post-survey yielded more thorough student responses. Additionally, the procedure was modified multiple times during the lab to determine what methods were most effective. For example, lab procedure outlined microplastic removal using a spoon, but that proved to be slow and ineffective. Over time, a couple of different funnel and screen filtration methods were tried, and the screens proved most effective. This lab was very frustrating for students and their frustration is reflected in survey responses. It is worth noting that the lab was intended to be somewhat frustrating to illustrate the difficulties of ocean plastic cleanup.

Sixteen students responded to the post-laboratory surveys (see Table 11). These student responses were coded into seven different categories, some with multiple codes for a single response. The total number of coded responses is the *N* value to calculate percentages.

Table 11

Student Responses and Code Categories For "Why Do Plastic Containers Have Those Different Numbers Stamped on Them?" Post-Lab Survey

Question	Number of student responses	Number of coded responses
Name and Explain at Least Two Things That Went Well in Today's Laboratory.	16	29
Name and Explain at Least Two Things in the Experiment Today That Can be Improved to Create a Better Experience.	16	36
What Material was the Most Significant?	16	26
How Do You Foresee Using Material from This Unit in Your Future Classroom? If You Do Not Foresee Using the Material, Explain Why.	16	26

Note. Student responses are sorted into codes, with one response fitting multiple codes, leading to a larger number of coded responses.

When listing what went well in the laboratory experiment, over half of students discussed the density activities where they had to identify plastics using different solutions. A few students mentioned learning about plastic or their specific approach to the laboratory activities when listing what went well (see Table 12), and some students appreciated that the lab was purposefully difficult: "This made me realize how challenging it is to separate plastics into their types."

Table 12

Frequency and Response Post-Laboratory Survey "Why do Plastic Containers Have Those Different Numbers Stamped on Them?" Lab Question 1.

Code	Frequency *N* = 29	Percentage response
Different section of lab (not applicable)	2	7%
Lab details	2	7%
Plastic examples	4	14%
Identifying floating plastics and differences. similarities	11	38%
Learning about plastic	3	10%
Sorting ease or difficulty	3	10%
Part 3, microplastics	4	14%

Note. Lab Question 1is "Name and Explain at Least Two Things That Went Well in the Laboratory Today."

There were many logistical challenges during the filtration and separation of microplastics activity. As a result, many students had helpful suggestions for improving the laboratory procedure. Survey answers were categorized and sorted into codes. The most common issue identified by the students was time constraints from a mix of tedious procedures or lack of adequate lab stations. This was mentioned in around 44% of responses (see Table 13). Another timing issue occurred while students tried to rinse solution residue off microplastic pieces. This part of the experiment was supposed to be frustrating to emphasize the difficulty of ocean cleanup, but the problems listed here made it more frustrating for students than intended. About 11% of student responses suggested using fewer types of plastic samples to make the lab less frustrating. Additionally, another 11% of responses gave direct suggestions to improve the laboratory procedure:

- "Maybe a slotted spoon to gather plastics and a drying rack?"
- "It might be effective to not label each of the plastics and then have us sort them all into their types."

Table 13

Frequency and Response Post-Laboratory Survey "Why Do Plastic Containers Have Those Different Numbers Stamped on Them?" Lab Question 2.

Code	Frequency *N* = 36	Percentage response
Different section of the lab, uncertainty, misc.	1	4%
Issues with time	9	25%
More lab stations, more materials	7	19%
Straining/ rinsing	7	19%
Suggestions	4	11%
Tedious	4	11%
Too many plastics samples	4	11%

Note. Lab Question 2 is "Name and Explain at Least Two Things in the Laboratory Experiment Today That Can be Improved to Create a Better Experience."

When asked what material from the laboratory they most identified with, some students responded with various physical materials, as they did for "Why do we need a better plastic?" To prevent this misunderstanding happening in future lab post-surveys, I changed the survey to read "concept" instead of "material". I thought it was interesting that some students went into more detail, describing what plastic they personally use and how. This is likely connected to the misunderstanding where students were listing physical items from the lab that are important to them. Although students were incredibly annoyed by the microplastic density experiment, some students did list it as what stuck out the most to them:

- "This can give us a visual 'model' of how the plastics can hide in the water. It can also show how difficult it is to get them out."
- "Each time we filtered in part 3 disturbed me thinking of the oceans."

When asked if and how they might use this lab in their future classrooms, most students stated that they would use it in some manner. About 27% of the responses indicated that they would use a simplified version of the lab in their classrooms, and another roughly 27% of the responses indicated that they would use this experiment to teach about concepts relating to either plastics or pollution (see Table 14). A few students did mention that they would use this lesson to teach the concept of density as well. While it was more frustrating for the students in the moment than some of the other labs, this experiment made a lasting impression on several of the students.

Table 14

Frequency and Response Post-Laboratory Survey "Why Do Plastic Containers Have Those Different Numbers Stamped on Them?" Lab Question 4.

Code	Frequency $N = 26$	Percentage response
Will teach/ Positive lab feedback	4	15%
Teach density	3	12%
Teach about plastic usage	2	7.5%
Use as demonstrations/ additional accompanying activities/projects	2	7.5%
Simplify or shorten material	7	27%
Teach environmental advocacy	3	12%
Teach about plastic harming the environment	5	19%

Note. Lab Question 4 is "How do You Foresee Using Material from This Unit in Your Future Classroom? If You Do Not Foresee Using This Material, Explain Why."

Are Mushrooms the New Styrofoam?

In the lab "Are Mushrooms the New Styrofoam?" students made living "styrofoam" out of mushrooms. Sixteen students responded, but one student skipped a question. These student responses were coded into different categories, some with multiple codes for a single response. The total number of coded responses is listed in Table 15. The total number of coded responses is the *N* value to calculate percentages.

Table 15

Student Responses and Coded Responses For "Are Mushrooms the New Styrofoam?" Post-Lab Survey

Question	Number of student responses	Number of coded responses
Name and Explain at Least Two Things That Went Well in Today's Laboratory.	16	33
Name and Explain at Least Two Things in the Experiment Today That Can be Improved to Create a Better Experience.	16	32
What Material was the Most Significant?	16	18
How do You Foresee Using Material from This Unit in Your Future Classroom? If You do not Foresee Using the Material, Explain Why.	16	27

Note. Student responses are sorted into codes, with one response fitting multiple codes, leading to a larger number of coded responses.

When asked what went well during the lab, students had a wide variety of responses. Some specifically mentioned that the activity was fun, and 28% specified that the making of the material went well (see Table 16). Three students stated that the instructions were noticeably clear. Most students found this activity relatively easy to accomplish, and 18% commented positively on the potential for this material to replace styrofoam.

Table 16

Frequency and Response "Are Mushrooms the New Styrofoam?" Post-Laboratory Survey Question 1

Code	Frequency *N* = 33	Percentage response
Different section of the lab, uncertainty, misc.	3	9%
Fun	4	12%
Designing their molds from the mushroom material	6	18%
Making the mushroom material wend well	9	28%
Connection to styrofoam replacements, uses	6	18%
Finished product properties	5	15%

Note. Post-Laboratory Survey Question 1 is "Name and Explain at Least Two Things That Went Well in the Laboratory Today."

While 25% of students listed that they felt making the material went well in response to Question 1, in contrast, 42.9% stated that they struggled with either the product or directions needed to achieve optimal success (See Table 17). As with some of the other labs, providing students enough time to complete the assignment without feeling rushed was a challenge. Four students indicated that the instructions needed more clarity, despite other students citing the instructions as a strength in answers to the previous question. This leads me to believe that there may be a specific section of otherwise clear instructions that should be revised.

Table 17

Frequency and Response "Are Mushrooms the New Styrofoam?" Post-Laboratory Survey Question 2

Code	Frequency N = 32	Percentage response
Different section of the lab, uncertainty, misc.	7	22%
Issues with product	8	25%
More detailed directions	4	12.5%
Additional explanations	4	12.5%
Suggestions for additional features or testing	6	19%
Scent	3	9%

Note. Post-Laboratory Survey Question 2 is "Name and Explain at Least Two Things in the Laboratory Experiment Today That Can Be Improved to Create a Better Experience."

When students were asked to indicate what material or concept in the module was the most significant to them, most of the students (56%) chose the existence of eco-friendly plastic alternatives (see Table 18). Another 44% indicated that the most significant concept was the process of making the material from Ecovative Design (the company based off these styrofoam alternatives) or the properties of the specific product used in the lab. The improved wording meant that this question did not have the same type of misunderstanding that occurred when this question was asked in the first two labs.

Table 18

Frequency and Response "Are Mushrooms the New Styrofoam?" Post-Laboratory Survey Question 3.

Code	Frequency *N* = 18	Percentage response pre-survey
Styrofoam, plastic alternative	10	56%
Ecovative design	8	44%

Note. Post-Laboratory Survey Question 3 is "What Material/Concept in This Module Was the Most Significant to You? Explain."

When asked how this lab might be used in their future classrooms, students identified five different ways they saw it adding to their curriculum. The most common answer, with 30%, was to teach about alternatives to standard plastic (see Table 19). The next most common response, with 26%, was that they felt they could use this lab to modify or add onto their regular lesson plans. Another common response (22%) was using it as a hands-on student learning experience. The wide variety of responses indicate that this lab could be used in multiple contexts and has a lot of versatility for elementary classrooms:

- "I would love to use this lab as a way of talking about alternative choices humans can make to help preserve our resources."

Table 19

Frequency and Response "Are Mushrooms the New Styrofoam?" Post-Laboratory Survey Question 4.

Code	Frequency $N = 27$	Percentage response
Use to teach about plastics/plastic alternatives	8	30%
Hands-on lesson	6	22%
Modify material and add to lesson	7	26%
Use as a class demonstration	2	7%
Use to teach environmentally friendly choices	4	15%

Note. Post-Laboratory Survey Question 4 is "How Do You Foresee Using Material From This Unit in Your Future Classroom? If You do not Foresee Using the Material, Explain Why."

What Kind of Biopolymers Do You Want to Make?

In the lab "What Kind of Biopolymers Do You Want to Make?", students were asked to create their own custom polymers. Sixteen students responded to the post-laboratory survey. These student responses were coded into different categories, some with multiple codes for a single response. The total number of code categories is listed in Table 20. The total number of categorized responses is the *N* value to calculate percentages.

Table 20

Student Responses and Coded Responses For "What Kind of Biopolymers Do You Want to Make?" Post-Lab Survey

Question	Number of student responses	Number of coded responses
Name and Explain at Least Two Things That Went Well in Today's Laboratory.	16	27
Name and Explain at Least Two Things in the Experiment Today That Can be Improved to Create a Better Experience.	16	24
What Material was the Most Significant?	16	21
How do You Foresee Using Material from This Unit in Your Future Classroom? If You do not Foresee Using the Material, Explain Why.	16	22

Note. Student responses are sorted into codes, with one response fitting multiple codes, leading to a larger number of coded responses.

When asked to name two things that went well in the laboratory, there were several common responses. A quarter of respondents indicated that they enjoyed the lab, with 35% stating that they felt the procedure went well. Additionally, 25% indicated that they liked the possible variations with the many different additives and starches (see Table 21):

- "The idea of touching and tearing gives you a real feel of how these polymers properties could be used in real life applications."

- "It was interesting to see all the variation in the plastics. Thinking of where I had seen similar substances was cool and thought provoking. I could think of more than I would have thought."

Table 21

Frequency and Response Percentage for Post Laboratory-Survey "What Kind of Biopolymers Do You Want to Make?" Lab Question 1.

Code	Frequency *N* = 27	Percentage response pre-survey
Different section of the lab, uncertainty, misc.	1	4%
Enjoyed lab	7	25%
Differences with additives/starches	7	25%
Procedure went well	9	35%
Possible biopolymer applications	3	11%

Note. Post Laboratory-Survey "What Kind of Biopolymers Do You Want to Make?" Lab Question 1 is "Name and Explain at Least Two Things That Went Well in the Laboratory Today."

When asked to identify two things that could be improved, there were multiple suggestions, with time mentioned in a third of responses (see Table 22). Eight students indicated that they needed more time for this lab. A few students mentioned that they struggled with the directions or that they had issues with the products, but most of the other feedback proposed ways to expand student choices and make the assignment more open-ended. Suggestions like adding more choices in starches or other variables and having even more samples available are less about addressing issues with the current assignment and more about expanding the scope and open-endedness of the lab.

Table 22

Frequency and Response Percentage for Post-Laboratory Survey "What Kind of Biopolymers Do You Want to Make?" Lab Question 2.

Code	Frequency *N* = 24	Percentage response pre-survey
Confusing directions. Need more Information	3	12%
More time needed	8	33%
More choices in starches/additives/ variables	5	21%
Product problems	4	17%
More/larger samples	4	17%

Note. Post-Laboratory Survey "What Kind of Biopolymers Do You Want to Make?" Lab Question 2 is "Name and Explain at Least Two Things in the Laboratory Experiment Today That Can Be Improved to Create a Better Experience?"

Table 23

Frequency and Response Percentage for Post-Laboratory Survey "What Kind of Biopolymers Do You Want to Make?" Lab Question 3.

Code	Frequency N = 21	Percentage response
Plastic replacement	5	24%
Concept of different reactants creating different properties	8	38%
Biopolymer process	3	14%
Additives causing differences	3	14%
Different biopolymer applications	2	10%

Note. Post-Laboratory Survey "What Kind of Biopolymers Do You Want to Make?" Lab Question 3 is "What Materials/Concepts in This Module Were the Most Significant to You? Explain."

The responses to question three of the survey (see Table 23) indicate that the concept of different reactants creating diverse properties was the most common significant student take-away from this assignment. Other responses indicated an interest in the polymer process or how additives caused changes in the way a polymer develops. Student responses reveal that they gained a fuller understanding of the polymer development process and found it most significant:

- "Understanding how biopolymers can be made and how it is challenging for them to be strong enough to use."
- "Knowing that there are so many variables that can impact the results of a material."

When asked if and how they might use this material in their future classrooms, the responses were varied. Three students indicated that they would not use this lab, either because they felt their students were too young or had other issues with completing this lab (see Table 24). Four students thought that they would modify the lesson to make it more accessible to their younger students. Of the students planning to use an unmodified version of the lab in their classrooms, 27% would use it to teach how polymers were created, while 14% planned to use it to teach about the need to reduce plastic usage. Additionally, four students stated that they would like to do this activity in their future classrooms because they felt that it was fun and engaging:

- "I think I would alter this so that my students were trying to create a product that would replace petroleum-based oils."
- "I would use this in the classroom to show students what a biopolymer is and what it could be used for."

Table 24

Frequency and Response Percentage for Post-Laboratory Survey "What Kind of Biopolymers do You Want to Make?" Lab Question 4.

Code	Frequency *N* = 22	Percentage response pre-survey
Students would enjoy/Fun	4	18%
Would not use/Too young/Issues with the lab	3	14%
Discuss how mixing two materials can make a new product (polymer) and additives	6	27%
Teach to reduce plastic	3	14%
Modify procedure/lesson/grade	4	18%
Discuss application	2	9%

Note. Post-Laboratory Survey "What Kind of Biopolymers do You Want to Make?" Lab Question 4 is "How Do You Foresee Using Material from This Unit in Your Future Classrooms? If You Do Not Foresee Using This Material, Explain Why."

Chapter 6: Laboratory Reports

Students were assigned lab reports to complete during and after the laboratory period. All 17 that consented to data sharing participated in this qualitative analysis mainly because it was part of their grade for the course. Students were given a week to complete the report and turn it in at the next lab period. For the laboratory reports used in this study, students were mainly given short answer questions. The amount of lab report questions that were related to material in this study varied depending on the length of the lab and how many other experiments were scheduled for the class period that day. Critical thinking questions relating to this research were transcribed into intelligent transcription, which removes short phrases like "um," receptive phrases, and digressions from the interview questions (Golota, 2018). The transcriptions of these critical thinking questions were then qualitatively coded based on trends in student answers.

This data was collected and analyzed to determine how students felt about the course material while they were learning it. This is a process that cannot be seen in any other type of data collection I used for this research. In addition, lab report data shows how students reacted to the material when they had a week to process it, although some surveys were turned in after a week as well. Each laboratory had questions relating to this research, but not all questions involved critical thinking. The questions with thorough responses were analyzed and included here. Fifteen students submitted survey answers, but one student skipped a question. The student responses were coded into different categories, some with multiple codes for a single response. The total number of coded responses is listed in Table 25 and is the *N* value used to calculate percentages.

Table 25

Student Responses and Coded Responses for Laboratory Report Questions

Question	Number of student responses	Number of coded responses
Why do you think the current plastic is harmful to the environment?	15	21
How does experiencing a small bit of the challenges involved in separating unmarked plastics make you think about how you could do things differently regarding plastic usage in your home or school? What changes could you implement?	14	34
Using your observations, those from other groups, as well as the demo samples Tori prepared, how does this activity illustrate the main concept of the DCI?	14	40

Note. Student responses are sorted into codes, with one response fitting multiple codes, leading to a larger number of coded responses.

The laboratory "Why Do We Need a Better Plastic?" focused on finding information in the readings that talked about recycling and the environmental impact of plastic. One question in the lab report asked students to share their own view on the issue after completing the reading, "Why do you think the current plastic is harmful to the environment?" All responses fit into three main categories, seen in Table 26, so student answers were consistent with the reading. Just under half of the response statements mentioned that plastic takes a long time to degrade into microplastics, which do not completely biodegrade. The other responses were nearly split in their focus on how plastics give off chemicals and how plastic harms both the environment and those who live in it.

Table 26

Code for "Why Do We Need a Better Plastic?" Laboratory Report Question

Code	Frequency $N = 21$	Percentage response
Long degradation time	10	47.6%
Harms people and animals	6	28.6%
Gives off chemicals	5	23.8%

Note. Student answers were consistent with class reading so only three codes were needed.

In the lab report for "Why Do Plastic Containers Have Those Different Numbers Stamped on Them?" students were asked how experiencing some of the challenges involved in separating micro-plastics made them think about their own plastic usage. Specifically, they were asked to reflect on what they could do differently at home or school in terms of plastic usage. The 14 student responses were categorized into 34 different statements and fragments that fit into eight qualitative codes, shown in Table 27.

One code category stood out more than the rest: the student responses that emphasized that it was difficult to sort plastics, with 26.5% of responses. With 17.6%, the second most common response was to reduce their plastic usage. Recycling or reusing more plastic had 14.7% of responses, keeping the "reduce, reuse, recycle" motto in the top three most common reactions to this lab. In direct response to the difficulty of separating unmarked plastic, 11.8% of students said that they would sort their recycling at home. Both the idea to buy sustainable packaging and the effort of teaching people we know why and how to recycle more had 8.8% of responses. Tied for the smallest percentage of responses at 5.9%, the ideas to improve school recycling and buy less plastic in general were also proposed.

Table 27

Code for "Why do Plastic Containers Have Those Different Numbers Stamped on Them?" Laboratory Report Question

Code	Frequency *N* = 34	Response percentage
Recycle/reuse more plastic	5	14.7%
Use less plastic	6	17.6%
Difficult to sort plastics	9	26.5%
Buy less types of plastic	2	5.9%
Sort recycling at home	4	11.8%
Buy sustainable packaging	3	8.8%
Teach family and students to recycle more, and why	3	8.8%
Improve school recycling	2	5.9%

Note. Students were asked to reflect on their own plastic usage and come up with ideas for what they could do.

At the end of the second half of "What kind of biopolymer do you want to make?", students were asked how their and other groups' observations of the biopolymers and styrofoam alternative illustrated the main concept of the disciplinary core ideas listed here:

- NGSS K-2 DCI for PS1.A: Structure and Properties of Matter states "different properties are suited to different purposes."
- NGSS 3-5 DCI for PS1.B: Chemical Reactions states "when two or more different substances are mixed, a new substance with different properties may be formed."

Student responses fit into five qualitatively coded categories, seen in Table 28. Two categories, totaling half of the responses, explained how either the biopolymer or mushroom styrofoam starting material properties differed from the properties of the final product. Roughly another 33% of responses discussed how the polymers they made could have different uses in everyday life based on these properties. The remaining percentage discussed how the specific biopolymers differed and how all the materials the class made were environmentally friendly.

Table 28

Code for "What Kind of Biopolymer Do You Want to Make?" Laboratory Report Question

Code	Frequency *N* = 40	Percentage response
Biopolymer starting materials have different properties than their products	14	35.0%
Mushroom mulch starting materials have different properties than their product	6	15.0%
The polymers that were made can have different uses in everyday life based on their properties	13	32.5%
Specifically, how the various polymers differed	5	12.5%
The materials made were environmentally friendly	2	5.0%

Note. Students were asked to relate labs from this study to the NGSS standards "NGSS K-2 DCI for PS1.A" and "NGSS 3-5 DCI for PS1.B."

Chapter 7: Focus Groups

Focus groups were the final form of data collection for this study. Students earned extra credit, and 14 of the 17 students participated. The interviews were standardized, open-ended with four questions written in advance. (See in Appendix N.) Follow-up questions were asked as needed. Although two follow-up questions are listed with the interview questions, they are not reported here. The first question asked students what changes they would make to the laboratories, but results were similar to the responses given to the same question in the post laboratory surveys. I suspected this but wanted to ask anyway to see if anything new was mentioned. The other question not analyzed for this study asks students how they feel about teaching material to visiting fifth graders, but as the visit was canceled and students did not have significant concerns, it was no longer relevant. The interviews were audio and video recorded and transcribed later using verbatim transcription. These were then translated to intelligent transcriptions and coded qualitatively based on trends in student responses.

These interviews were conducted to determine how students felt about the sequence of labs throughout the semester as a whole and how their experience lined up with one of the guiding research questions. Specifically, how these laboratories impacted their relationship with plastics, and if they wanted to teach the material in their own classrooms someday. While there is data to determine this from their pre/post-surveys, post-laboratory surveys, observations, and class material, I thought it was also important to give the students a chance to answer directly. This gave me the opportunity to get their opinions outside of the traditional classroom setting and not immediately at the end of a class period. Students had time to think about their responses and reflect on their experience throughout the semester. They also built off of each other's stories and comments, which gave a better description of student experiences as a whole. Responses shortened for content and length are shown below their respective data tables. Not all responses are included, as some did not have significant content or were about laboratories not included in this study. The following sections are each titled with a different focus group question, which subsequently present the data for that question. Answers to questions were recorded for all 14 participants, but one participant was reluctant to answer all the questions asked during the interview. These student responses were coded into different categories, some with multiple codes for a single response. The total number of coded responses is listed in Table 29 and is the *N* value to calculate percentages.

Table 29

Student Responses and Coded Responses for Focus Group Questions

Question	Number of student responses	Number of coded responses
Which laboratory did you find the most interesting and why?	14	26
What Is Your Relationship with Disposable Plastic Going to Look Like Going Forward? Has It Changed?	13	45
How Do You Feel About Teaching This Material in Your Own Classrooms?	13	21

Note. Student responses are sorted into codes, with one response fitting multiple codes, leading to a larger number of coded responses.

Which Laboratory Did You Find the Most Interesting and Why?

Even though a lot of students were very frustrated with the "Why Do Plastic Containers Have Those Different Numbers Stamped on Them?" lab activities, three students still listed it as one the labs that interested them the most (see Table 30). This activity was purposefully irritating to illustrate how tedious and difficult it is to remove plastics from our oceans:

- "It gave me a better idea of how it's not that easy to recycle things and how it's important to know what can be recycled and what can't be recycled."
- "... [about microplastics filtering] you wanna go and do that on a macro level and sort through all of this?... I've already been pretty good about recycling, but especially after doing that lab. I go out of my way to go and recycle. I hold on to stuff no matter what. I had a tendency to kind of do that, but now I'm really … all about it."
- "It simulated the ocean or different waterways [to] see how hard it is to get rid of, or clean up the pollution that's already out there."

Table 30

Frequency and Response Percentage of Focus Group Interview Question 1

Code	Frequency *N* = 26	Percent response
Why do plastic containers have those different numbers stamped on them?	3	11.5%
Are mushrooms the new styrofoam?	4	15.5%
Water pollutant cleanup	1	3.8%
What kind of biopolymers do you want to make?	8	30.8%
Additional anecdotes about laboratories	9	34.6%
Lab not included in this study	1	3.8%

Note. Students were asked which lab they found the most interesting and why.

"Are Mushrooms the New Styrofoam?" was the class's second favorite laboratory. Although not many students could pinpoint exactly why they liked it so much, they just seemed to think it was a fun activity. A couple students had more in-depth comments, but that is it:

- "I was surprised how hard it was when it turned out. I was not expecting it. … It was interesting."
- "...this is just literally mulch but [adding] the flour and mushroom just to make that fungus type thing to actually have that as [styrofoam]. I would much rather

see that than styrofoam. I thought that was the most applicable thing that we could do."

- "It was my favorite, too."
- "It was something I've never seen or heard about before, so it was pretty interesting...There's not a certain part I thought was the most interesting, it was all cool to see and do."

The "What Kind of Biopolymer Do You Want to Make?" laboratory was the most popular by far with 30.8% percent. Some students were surprised that they could make biopolymers from materials they had in their kitchen pantry. Several participants commented on the differences between their biopolymers with and without the glue additive. Many did not anticipate the increased hardness, as mentioned previously:

- "I really liked the biopolymer one… that one was fun… then you could see the different textures that adding an additive has."
- "I thought it was interesting that you could make a thing out of something you don't usually associate with plastic…. it was just a fun one."
- "I think it was interesting to see what people chose to do, and then how much the one tablespoon of glue changed the whole thing."
- "The polymer one was really cool because of how it kind of turned out. One went from pretty movable to [that] you can't do anything with the other. It was cool to think about what those could be used for."
- "Making our own polymers and seeing what the differences were between groups, [and] for what it could be applied to, as well. Like, do you need a rubbery [one] versus something stronger and more solid."

There were a lot of anecdotes and suggestions about the labs in this section of the focus group interviews. Many of these anecdotes were small lists of things they disliked about the labs that reiterated the post laboratory survey responses. A handful of students shared various vague opinions of the labs, mainly stating that they were “fine,” or “okay”:

- “I think for [biopolymer lab] it would have been nice to have some sort of example of what’s been made before, because one of the questions on the lab report was ‘what can you make from your polymers’ and it gave examples like fishing line, Tupperware…”

What Is Your Relationship with Disposable Plastic Going to Look Like Going Forward? Has It Changed?

Nearly every focus group participant said their relationship with single-use, non-durable/disposable plastics like soda bottles has changed over the course of the semester to some degree, only one student disagreed (see Table 31). This student cited the lack of change to the fact that they were an avid recycler before this course. Four students said that they had already thought about their relationship with disposable plastics:

- “Yeah, I'd probably say the same thing. It hasn't drastically changed, but I am way more conscious of it, yeah.”
- “I mean I always knew it was an issue, but [doing] different activities and stuff really brought it to light. We have a super amazing material that we made and we're using it for straws, and wrapping produce, and crap like that.”
- “I think about what I’m using and what to do with it once I’ve finished with it, whether I reuse or recycle it.”
- “So, for me, I am conscious now. It just happened overnight.”

Table 31

Frequency and Response Percentage of Focus Group Interview Question 2

Code	Frequency *N* = 45	Percent response
Think about plastic about plastic usage/ recycling more	19	42.2%
No change	1	2.2%
Already think about it	4	8.9%
Clearly changed	5	11.1%
Use of reusable liquid/food containers, use of the disposable versions	5	11.1%
Recycle more, hang onto things to recycle	4	8.9%
Involve others in work and/or daily life in plastic use/recycling efforts	3	6.7%
Difficult and/or hard requirements	2	4.4%
Additional anecdotes	2	4.4%

Note. Students were asked what their relationship with disposable plastic was like and how it would change after completing the course.

Students mentioned several different habits they have broken or started as their outlook on plastics has changed. They use more reusable bottles, involve others in their habits, and hang onto items to recycle later:

- "I stopped using plastic bags and forced myself to just try to carry things out there... And then carrying trash around in my pockets. Literally I will grab [it] instead of just throwing it out I will grab and wait and sit there and have all this stuff clutter up my pockets until I find recycling”

- “Well personally, I work at a Starbucks… So, I press other people. Like, ‘Yeah, I know you have a reusable cup, why aren't you using it?’ I just mess with them more about it now. I've been more conscious about it.”
- “I give out one straw as I'm bartending or serving, I give out one straw per cup, and then I leave the empty refill and bring a fresh one and allow them the time to grab their straw and move it over to take it away.”
- “I was gonna get a 24 pack of plastic water bottles the other day and I was like no, I don't need to do that, I have a water bottle at my dorm! So, I was really proud of myself, and I really feel like it's changed.”
- “I'm a really bad plastic water bottle person. I'll drink like a million of them, so I've been trying to use a metal can, reusing it, but it's tricky when you're on the go, you know. But I always try.”

How Do You Feel About Teaching This Material in Your Own Classrooms?

Nearly all focus group participants said they would be interested in teaching the curriculum presented in this study in some form. Some students appeared to be interested in all the curriculum, others were interested in teaching the concept instead of the laboratory activities:

- “Yeah, I think I would take a lot of these things into my classroom. Because I feel like a lot of kids hear about the use of plastic and stuff. But, this dives into the science behind it, which I think is really important to talk about”
- “I just remember a lot of the labs had multiple parts, and I would take parts from it… just kinda take pieces of some of the labs, with the concept.”

There were two labs that were clear favorites for elementary curriculum, the "Why do plastic containers have those different numbers stamped on them?" And the "How long until it's gone" timeline activity" (see Table 32):

- "I really like the timeline one that we're going to be doing on visitation day. I had to make a lesson plan for one of my other classes, so I actually used that in it. So, I could totally see myself using that for my class."
- "I think in an elementary classroom the microplastics one would be most beneficial to teach recycling and stuff."

Table 32

Frequency and Response Percentage of Focus Group Interview Question 3

Code	Frequency *N* = 21	Percent response
Yes	5	23.8%
"How long until it's gone" Timeline activity	5	23.8%
Why do plastic containers have those different numbers stamped on them?	4	19.0%
Are mushrooms the new styrofoam?	1	4.8%
Difficult	1	4.8%
Water cleaning activity	1	4.8%
Importance of teaching the material	2	9.5%
Additional anecdotes	2	9.5%

Note. Students were asked if they were interested in teaching material from this study in their classes someday.

Chapter 8: Conclusions

This study shows that introducing polymer-focused environmental education into general chemistry coursework for pre-service elementary teachers effectively improves student understanding of the importance and extent of polymer pollution. In addition, this curriculum implementation resulted in more interest from preservice teachers to teach these topics and their respective laboratories in their own classrooms someday.

Pre/post-course surveys indicated that while most students were already environmentally conscious and recycled often, the laboratory sequence still impacted both students' attitudes and behaviors. For some students, there was a shift from seemingly passive environmentalism to more active efforts to prevent plastic pollution. This change is reflected in the data regarding student recycling habits gathered by the pre/post course surveys. The percentage of students that indicated that they "nearly always" recycle plastics increased by 12% after the conclusion of the laboratory sequence (see Figures 6 and 7). Paper and aluminum recycling frequency were reported to have increased by 8% and 17%, respectively (see Figures 8 through 11). It is worth noting that self-reported data is potentially less reliable due to the potential for the students to have felt social pressure to state they have increased recycling. However, even in a case of a student mis-reporting their habits, this would still indicate that they feel that they should be recycling more. While the majority of students demonstrated limited change in recycling habits, a few students experienced a substantial attitude shift, as they went from thinking "I will recycle something if it's convenient" to "I will hang onto this until I am able to recycle it."

Having the opportunity to observe the laboratories as they were taught gave me valuable information about student learning processes. I observed learning progress in action, clear comprehension of curriculum, and classroom behavior that shows potential for student achievement. Difficulties with laboratory materials pushed students to work with other sets of lab partners to and think critically to develop feasible solutions to problems. These difficulties also pushed students to pull knowledge from course material to explain issues, like when they reasoned plastics were not floating due to a density increase from paper residue's water absorption. These observations demonstrate understanding of polymeric environmental concerns and give insight on possible laboratory improvements.

Laboratory reports provided the opportunity to ask more in-depth questions and encourage critical thinking about the environmental topics presented. We saw well thought out answers that looked at the root of these issues. When students were asked to reflect on their plastic usage and what they could change, they suggested the use of sustainable packaging, improving the school's recycling, and teaching others to recycle more and how. These responses were in addition to the standard "reduce, reuse, recycle" responses. When presented with in depth questions, students not only show understanding of polymeric environmental impact, but feasible solutions to these problems as well.

Responses from post-laboratory surveys gave specific details about what worked and what can be improved for the next iteration of the curriculum. Although two labs stood out as clear favorites, each laboratory had at least some content students found engaging and impactful. In continuing to develop these laboratories, focusing on these areas that students found interesting while cutting areas of frustration will improve laboratory effectiveness and the likelihood of the pre-service teachers teaching these labs in their future classrooms. However, even with the elements that students found frustrating in some of the labs, every student indicated that they intend to teach one or more of the included labs in their future classrooms. This shows that including polymer-focused environmental labs in the general chemistry curriculum for pre-service teachers generates interest in including this material in their future classrooms.

Focus group interviews showed that the laboratories did increase student understanding of the importance of polymer education and addressing the issue of plastic pollution. The focus groups also added a lot of additional detail, clarification, and personality to improve this study. They shared ideas for improving the curriculum in this lab sequence and what concepts they enjoyed or found particularly impactful. Participants reflected on their relationships with disposable plastics, and many of them listed the new recycling habits they had begun to form since the start of the course. Most students were interested in teaching the laboratory activities designed for this study, and even those who were not interested in teaching a particular laboratory still believed it was important to teach the concepts included in that laboratory. They also discussed the desire to modify laboratory procedures to suit the needs of their future classes. The labs that students said they wanted to teach the most were “Why Do Plastic Containers Have Those Different Numbers Stamped on Them?” and “How Long Until it’s Gone?” Students attributed this to the visual impact the floating microplastics had on them when considering oceans, as well as the clarity and simplicity of the trash decomposition timeline.

The data gathered in this study supports that inference that the lack of polymer and plastic-pollution based environmental education in K-5 settings can be remedied in part by teaching pre-service elementary teachers about these concepts and providing them with practical, hands-on labs that they can use in their classrooms. Running undergraduate polymer labs for pre-service teachers does increase the understanding of the importance of recycling and their desire to teach these concepts. They are most inclined to teach the laboratories that both ran smoothly and that they found personally impactful. After participating in the entire lab sequence, almost all the pre-service teachers indicated their intention to teach one or more labs in their future classrooms, so these labs are an effective way to encourage them to teach about polymers and the issue of plastic pollution.

There are two important and related takeaways from this study. The first is that comprehension of a problem does not always lead to action towards a solution. This is evidenced in student responses indicating understanding of the presented issues but no confident plans to include this information in future curriculum. The second takeaway is that imperfect success is still valuable. Importance is subjective, so each student is impacted by the presented data differently. Regardless of their desire to include the content in future curriculum, all students gained a better understanding of plastic pollution. When presented with data on plastic pollution, some students drastically changed their lifestyle, while others noted that there were other problems that should be considered first.

There are many different types of success in teaching. In an ideal world, every student exposed to this information would immediately make changes in their lifestyle and become activists for reforming the way we interact with polymers in society. Unfortunately, that is not a realistic expectation. Comprehension does not always lead to action. However, as more people become aware of these issues, more individuals and groups are motivated to make changes and step up to address the issue of plastic pollution.

I wanted to conclude this study with a student quote that struck me as an ideal mindset not only as a teacher, but as a researcher and everyday science advocate. “I think we're not going to be able to convince [students] to believe what we want them to believe, but we can give them as much information as possible so they … come to that conclusion themselves [that] it's an issue.”

Chapter 9: Future Work

I intend to continue working with this laboratory curriculum, or another iteration of it, as I begin my teaching career.

This study brings up further questions on ecophobia and pollution education. Based on post course survey responses that describe plastic pollution as an inevitable problem or too large or an issue for them to contribute to, a few students may have experienced ecophobia. I would like to evaluate student feelings of ecophobia throughout the semester to see what labs or what information causes students to feel overwhelmed, and what concepts need more explanation. It would also be interesting to test whether modifying labs with a "what you can do to help" practical take-away at the end of each lab influences ecophobia outcomes.

As I worked on this thesis project, I had the opportunity to research and present on environmental injustice with my research colleague, Mary Bautista. That presentation, as well as working with a classmate specializing in environmental injustice, truly inspired me. Environmental injustice focuses on those directly impacted by pollution. I would like to focus on solutions to pollution problems that also help highlight and correct issues of environmental injustice. Going forward, I intend to include environmental injustice in all pollution education I write as critical thinking questions in lab reports and an assigned project that requires students to choose one facet of environmental injustice and propose solutions.

I was given the opportunity to create my own course at Russellville Independent Highschool, which I simply titled "Environmental Science." This course, starting in the spring semester of 2021, will include this laboratory sequence as part of a focus on "Environmental Pollution and Possible Solutions." I intend to expand the curriculum to include types of polymer pollution other than plastic as well as non-polymer pollutants students are familiar with. This course will also include elements of environmental injustice education and community outreach to directly improve issues of pollution in the area. The primary goal of the course is to empower students to be actively engaged in recycling and protecting the environment both in the class and after.

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APPENDICES

Appendix A: IRB Acceptance Letter

EASTERN
MICHIGAN UNIVERSITY

University Human Subjects Review Committee

Sep 13, 2019 9:33 AM EDT

Victoria Hill
Eastern Michigan University, Chemistry

Re: Exempt - Initial - UHSRC-FY19-20-25 Polymer Chemistry Education for Nonmajors to Increase Student Awareness of Plastic Pervasiveness and Environmental Impact

Dear Victoria Hill:

The Eastern Michigan University Human Subjects Review Committee has rendered the decision below for Polymer Chemistry Education for Nonmajors to Increase Student Awareness of Plastic Pervasiveness and Environmental Impact . You may begin your research.

Decision: Exempt

Selected Category: Category 1. Research, conducted in established or commonly accepted educational settings, that specifically involves normal educational practices that are not likely to adversely impact students' opportunity to learn required educational content or the assessment of educators who provide instruction. This includes most research on regular and special education instructional strategies, and research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

Renewals: Exempt studies do not need to be renewed. When the project is completed, please contact human.subjects@emich.edu.

Modifications: Any plan to alter the study design or any study documents must be reviewed to determine if the Exempt decision changes. You must submit a modification request application in Cayuse IRB and await a decision prior to implementation.

Problems: Any deviations from the study protocol, unanticipated problems, adverse events, subject complaints, or other problems that may affect the risk to human subjects must be reported to the UHSRC. Complete an incident report in Cayuse IRB.

Follow-up: Please contact the UHSRC when your project is complete.

Please contact human.subjects@emich.edu with any questions or concerns.

Sincerely,

Eastern Michigan University Human Subjects Review Committee

Appendix B: Classroom Observation Informed Consent Form

Classroom Observation Informed Consent Form

The principal investigator in this study is Victoria Hill, a chemistry graduate student at Eastern Michigan University. Her faculty advisor is Dr. Amy Johnson, who also teaches the course involved in this study.

Project Title: Polymer Chemistry Education for Non-majors to Increase Student Awareness of Plastic Pervasiveness and Environmental Impact

Principal Investigator: Victoria Hill, Graduate Student Faculty Advisor: Dr. Amy Johnson, Ph.D., Professor of Chemistry

Invitation to participate in research

As a student taking CHEM 101: Chemistry for Elementary Teachers, you are invited to participate in this research study. Participation is entirely voluntary. Feel free to ask any questions regarding study participation.

Important information about this study

- The purpose of this study is to educate preservice elementary teachers about everyday polymer science and the subsequent effect of polymers on the environment, then studying the effect of this knowledge on their attitudes about these topics.

- Participation in this part of the study involves the principal investigator observing the laboratory.
- Risks in this study include a potential loss of confidentiality.
- The researchers will protect your confidentiality by using pseudonyms for publications.
- Research participation is voluntary. If you decide to participate, you may withdraw your participation at any time.

What is this study about?

The purpose of this study is to educate preservice elementary teachers about everyday polymer science and the subsequent effect of polymers on the environment, then studying the effect of this knowledge on their attitudes about these topics. This allows the teachers to be prepared to teach this material in their own classrooms.

What will happen if I participate in this study?

Participation in this study includes:

The laboratory period will be observed with note-taking, students will be referred to with pseudonyms instead of names in these notes.

What are the expected risks for participation?

The main risk in this study is the possible loss of confidentiality.

Are there any benefits to participating?

You will not directly benefit from research participation.

How will my information be kept confidential?

We intend to publish the results of this study. We will not publish any identifiable information about participants in the study.

Your personal information will be kept confidential. Your name will be changed to a pseudonym in observation notes.

The physical copies of the notes will be kept in a locked shelf and the electronic data will be kept in a password-protected file on a password protected computer.

We will do whatever we can to keep your information confidential, but cannot guarantee it. Other groups may have access to this data for quality control or safety purposes, including the University Human Subjects Review Committee, the Office of Research Development, or federal and state agencies that oversee the review of research. The University Human Subjects Review Committee reviews research for the safety and protection of people who participate in research studies.

If during the study we have any reason to believe child abuse, elder abuse is occuring, or if we have reason to believe that you are at risk for suicide or self harm, we have to report to the authorities as required by law. We will do everything we can to keep your information confidential, but it may be possible that we have to release your research information. We would not be able to able to protect your confidentiality.

Storing study information for future use

We will store your information for future study. This information will be labeled with a code, not your name. Your information will be kept in a password-protected or locked file.

In the future, we may share your information with other researchers without asking permission, but this will never contain information that could identify you.

Contact Information: If you have any questions about this research, you can contact the Principal Investigator, Victoria Hill at vhill7@emich.edu, or the professor and advisor Dr. Amy Johnson at ajohns82@emich.edu or 734-487-0426.

For questions about your rights as a research subject, contact the Eastern Michigan University Human Subjects Review Committee at human.subjects@emich.edu or by phone at 734-487-3090.

Voluntary participation

Participation in this study is voluntary. You may refuse to participate at any time with no penalty, loss, course enrollment, or effect on grades. If you leave, your information will be kept confidential. You may send a written request that your identifiable information be destroyed, but we cannot destroy any information that has already been published.

Signatures

____

Name of Subject

Signature of SubjectDate

I have explained the research to the subject and answered all their questions. I will give a copy of the signed consent form to the subject.

Name of Person Obtaining Consent

Signature of Obtaining ConsentDate

Appendix C: Pre/Post Informed Consent Form

Pre/Post Survey Consent Form

The principal investigator in this study is Victoria Hill, a chemistry graduate student at Eastern Michigan University. Her faculty advisor is Dr. Amy Johnson, who also teaches the course involved in this study.

Project Title: Polymer Chemistry Education for Non-majors to Increase Student Awareness of Plastic Pervasiveness and Environmental Impact

Principal Investigator: Victoria Hill, Graduate Student Faculty Advisor: Dr. Amy Johnson, Ph.D., Professor of Chemistry

Invitation to participate in research

As a student taking CHEM 101: Chemistry for Elementary Teachers, you are invited to participate in this research study. Participation is entirely voluntary. Feel free to ask any questions regarding study participation.

Important information about this study

- The purpose of this study is to educate preservice elementary teachers about everyday polymer science and the subsequent effect of polymers on the environment, then studying the effect of this knowledge on their attitudes about these topics.

- Participation in this part of the study involves filling out a survey about your attitude towards plastic pollution that will take around 2-3 minutes at the beginning and end of the semester.
- Risks in this study include a potential loss of confidentiality.
- The researchers will protect your confidentiality by using assigned codes instead of names during data evaluation.
- Research participation is voluntary. If you decide to participate, you may withdraw your participation at any time.

What is this study about?

The purpose of this study is to educate preservice elementary teachers about everyday polymer science and the subsequent effect of polymers on the environment, then studying the effect of this knowledge on their attitudes about these topics. This allows the teachers to be prepared to teach this material in their own classrooms.

What will happen if I participate in this study?

Participation in this study includes:

- Filling out a survey about your attitude towards plastic pollution that will take around 2-3 minutes at the beginning and end of the semester.

What are the expected risks for participation?

The main risk in this study is the possible loss of confidentiality.

Are there any benefits to participating?

You will not directly benefit from research participation.

How will my information be kept confidential?

We intend to publish the results of this study. We will not publish any identifiable information about participants in the study.

Your personal information will be kept confidential. You will be assigned a code we will use instead of your name during data evaluation.

The physical copies of the surveys will be kept in a locked shelf and the electronic data will be kept in a password-protected file on a password protected computer.

We will do whatever we can to keep your information confidential, but cannot guarantee it. Other groups may have access to this data for quality control or safety purposes, including the University Human Subjects Review Committee, the Office of Research Development, or federal and state agencies that oversee the review of research. The University Human Subjects Review Committee reviews research for the safety and protection of people who participate in research studies.

If during the study we have any reason to believe child abuse, elder abuse is occuring, or if we have reason to believe that you are at risk for suicide or self harm, we have to report to the authorities as required by law. We will do everything we can to keep your information confidential, but it may be possible that we have to release your research information. We would not be able to able to protect your confidentiality.

During the focus group, you will also be asked not to tell anyone outside of the focus group what was said during the session. We cannot guarantee that all participants will keep the discussions private.

Storing study information for future use

We will store your information for future study. This information will be labeled with a code, not your name. Your information will be kept in a password-protected or locked file.

In the future, we may share your information with other researchers without asking permission, but this will never contain information that could identify you.

Contact Information: If you have any questions about this research, you can contact the Principal Investigator, Victoria Hill at vhill7@emich.edu, or the professor and advisor Dr. Amy Johnson at ajohns82@emich.edu or 734-487-0426.

For questions about your rights as a research subject, contact the Eastern Michigan University Human Subjects Review Committee at human.subjects@emich.edu or by phone at 734-487-3090.

Voluntary participation

Participation in this study is voluntary. You may refuse to participate at any time with no penalty, loss, course enrollment, or effect on grades. If you leave, your information will be kept confidential. You may send a written request that your identifiable information be destroyed, but we cannot destroy any information that has already been published.

Signatures

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Name of Subject

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Signature of SubjectDate

I have explained the research to the subject and answered all their questions. I will give a copy of the signed consent form to the subject.

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Name of Person Obtaining Consent

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Signature of Obtaining ConsentDate

Appendix D: Post-Laboratory Surveys Informed Consent Form

Post-Laboratory Surveys Consent Form

The principal investigator in this study is Victoria Hill, a chemistry graduate student at Eastern Michigan University. Her faculty advisor is Dr. Amy Johnson, who also teaches the course involved in this study.

Project Title: Polymer Chemistry Education for Non-majors to Increase Student Awareness of Plastic Pervasiveness and Environmental Impact

Principal Investigator: Victoria Hill, Graduate Student Faculty Advisor: Dr. Amy Johnson, Ph.D., Professor of Chemistry

Invitation to participate in research

As a student taking CHEM 101: Chemistry for Elementary Teachers, you are invited to participate in this research study. Participation is entirely voluntary. Feel free to ask any questions regarding study participation.

Important information about this study

- The purpose of this study is to educate preservice elementary teachers about everyday polymer science and the subsequent effect of polymers on the environment, then studying the effect of this knowledge on their attitudes about these topics.

- Participation in this part of the study involves filling out a survey about your attitudes toward the experiments you complete that will take around 2-3 minutes at the end of each lab period.
- Risks in this study include a potential loss of confidentiality.
- The researchers will protect your confidentiality by using assigned codes instead of names during data evaluation.
- Research participation is voluntary. If you decide to participate, you may withdraw your participation at any time.

What is this study about?

The purpose of this study is to educate preservice elementary teachers about everyday polymer science and the subsequent effect of polymers on the environment, then studying the effect of this knowledge on their attitudes about these topics. This allows the teachers to be prepared to teach this material in their own classrooms.

What will happen if I participate in this study?

Participation in this study includes:

- Filling out a survey about your attitudes toward the experiments you complete that will take around 2-3 minutes at the end of each lab period.

What are the expected risks for participation?

The main risk in this study is the possible loss of confidentiality.

Are there any benefits to participating?

You will not directly benefit from research participation.

How will my information be kept confidential?

We intend to publish the results of this study. We will not publish any identifiable information about participants in the study.

Your personal information will be kept confidential. You will be assigned a code we will use instead of your name during data evaluation.

The physical copies of the surveys will be kept in a locked shelf and the electronic data will be kept in a password-protected file on a password protected computer.

We will do whatever we can to keep your information confidential, but cannot guarantee it. Other groups may have access to this data for quality control or safety purposes, including the University Human Subjects Review Committee, the Office of Research Development, or federal and state agencies that oversee the review of research. The University Human Subjects Review Committee reviews research for the safety and protection of people who participate in research studies.

If during the study we have any reason to believe child abuse, elder abuse is occuring, or if we have reason to believe that you are at risk for suicide or self harm, we have to report to the authorities as required by law. We will do everything we can to keep your information confidential, but it may be possible that we have to release your research information. We would not be able to protect your confidentiality.

During the focus group, you will also be asked not to tell anyone outside of the focus group what was said during the session. We cannot guarantee that all participants will keep the discussions private.

Storing study information for future use

We will store your information for future study. This information will be labeled with a code, not your name. Your information will be kept in a password-protected or locked file.
In the future, we may share your information with other researchers without asking permission, but this will never contain information that could identify you.

Contact Information: If you have any questions about this research, you can contact the Principal Investigator, Victoria Hill at vhill7@emich.edu, or the professor and advisor Dr. Amy Johnson at ajohns82@emich.edu or 734-487-0426.
For questions about your rights as a research subject, contact the Eastern Michigan University Human Subjects Review Committee at human.subjects@emich.edu or by phone at 734-487-3090.

Voluntary participation

Participation in this study is voluntary. You may refuse to participate at any time with no penalty, loss, course enrollment, or effect on grades. If you leave, your information will be kept confidential. You may send a written request that your identifiable information be destroyed, but we cannot destroy any information that has already been published.

Signatures

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Name of Subject

____

Signature of SubjectDate

I have explained the research to the subject and answered all their questions. I will give a copy of the signed consent form to the subject.

____

Name of Person Obtaining Consent

Signature of Obtaining ConsentDate

Appendix E: Use of Course Material Informed Consent Form

Use of Course Material Consent Form

Project Title: Polymer Chemistry Education for Nonmajors to Increase Student Awareness of Plastic Pervasiveness and Environmental Impact

Principal Investigator: Victoria Hill, Chemistry Graduate Student

Invitation to Participate: As a student taking CHEM 101: Chemistry for Elementary Teachers, you are invited to participate in this research study. Participation is entirely voluntary. Feel free to ask any questions regarding study participation.

Purpose: The purpose of this study is to educate preservice elementary teachers about everyday polymer science and the subsequent effect of polymers on the environment, then studying the effect of this knowledge on their attitudes about these topics.

Study Procedures: We would like your permission to use the course assignments for research data. The classwork will be completed regardless of your participation in the study, and Dr. Johnson will not see this form until *after grades have been submitted*. Your grade will not be affected by your decision of whether or not to participate in this study.

Confidentiality and Risks: In order to reduce the potential for loss of confidentiality, your name will be removed from assignments and be given a confidential code. If any of your work is used for presentations, all identifiable information will be removed before publication. The research data will be stored in locked cabinets or in electronic password-protected computer files on a password-protected computer.

Benefits: You will not directly benefit from research participation in any way.

Contact Information: If you have any questions about this research, you can contact the Principal Investigator, Victoria Hill at vhill7@emich.edu, or the professor and advisor Dr. Amy Johnson at ajohns82@emich.edu or 734-487-0426.

Voluntary participation

Participation in this study is voluntary. You may refuse with no penalty, loss, course enrollment, or effect on grades.

Statement of Consent

I have read this form. I have had an opportunity to ask questions and am satisfied with the answers I received. I give my consent to participate in this study

Signatures

____

Name of Subject

____

Signature of Subject Date

I have explained the research to the subject and answered all their questions. I will give a copy of the signed consent form to the subject.

____

Name of Person Obtaining Consent

____

Signature of Obtaining Consent Date

Appendix F: Focus Group Interview Informed Consent Form

Focus Group Informed Consent Form

The principal investigator in this study is Victoria Hill, a chemistry graduate student at Eastern Michigan University. Her faculty advisor is Dr. Amy Johnson, who also teaches the course involved in this study.

Project Title: Polymer Chemistry Education for Non-majors to Increase Student Awareness of Plastic Pervasiveness and Environmental Impact

Principal Investigator: Victoria Hill, Graduate Student Faculty Advisor: Dr. Amy Johnson, Ph.D., Professor of Chemistry

Invitation to participate in research

As a student taking CHEM 101: Chemistry for Elementary Teachers, you are invited to participate in this research study. Participation is entirely voluntary. Feel free to ask any questions regarding study participation.

Important information about this study

- The purpose of this study is to educate preservice elementary teachers about everyday polymer science and the subsequent effect of polymers on the environment, then studying the effect of this knowledge on their attitudes about these topics.

- Participation in this part of the study involves a half hour focus group.
- Risks in this study include a potential loss of confidentiality.
- The researchers will protect your confidentiality by using pseudonyms for publications and asking participants to keep the focus group discussions confidential.
- Research participation is voluntary. If you decide to participate, you may withdraw your participation at any time.

What is this study about?

The purpose of this study is to educate preservice elementary teachers about everyday polymer science and the subsequent effect of polymers on the environment, then studying the effect of this knowledge on their attitudes about these topics. This allows the teachers to be prepared to teach this material in their own classrooms.

What will happen if I participate in this study?

Participation in this study includes:

- A focus group that will take around 30 minutes with 3-4 people in each group, along with the investigator to facilitate.

We would like to audio and video record the study to ensure accurate transcription of the interview. If you are recorded, it will be possible to identify you. The recordings will be stored securely after transcription is complete. If you do not wish to be recorded, you cannot participate in the focus groups, but may participate in the other parts of this study.

What are the expected risks for participation?

The main risk in this study is the possible loss of confidentiality.

If any questions in the focus group make you uncomfortable, you can choose not to answer. If you are upset, please inform the investigator right away.

Are there any benefits to participating?

You will not directly benefit from research participation.

How will my information be kept confidential?

We intend to publish the results of this study. We will not publish any identifiable information about participants in the study.

Your personal information will be kept confidential. The audio and video recordings will be transcribed and then securely stored. Your name will be changed to a pseudonym in the transcription.

The physical copies of the focus group transcripts will be kept in a locked shelf and the electronic data will be kept in a password-protected file on a password protected computer.

We will do whatever we can to keep your information confidential, but cannot guarantee it. Other groups may have access to this data for quality control or safety purposes, including the

University Human Subjects Review Committee, the Office of Research Development, or federal and state agencies that oversee the review of research. The University Human Subjects Review Committee reviews research for the safety and protection of people who participate in research studies.

If during the study we have any reason to believe child abuse, elder abuse is occuring, or if we have reason to believe that you are at risk for suicide or self harm, we have to report to the authorities as required by law. We will do everything we can to keep your information confidential, but it may be possible that we have to release your research information. We would not be able to protect your confidentiality.

During the focus group, you will also be asked not to tell anyone outside of the focus group what was said during the session. We cannot guarantee that all participants will keep the discussions private.

Storing study information for future use

We will store your information for future study. This information will be labeled with a code, not your name. Your information will be kept in a password-protected or locked file.
In the future, we may share your information with other researchers without asking permission, but this will never contain information that could identify you.

Contact Information: If you have any questions about this research, you can contact the Principal Investigator, Victoria Hill at vhill7@emich.edu, or the professor and advisor Dr. Amy Johnson at ajohns82@emich.edu or 734-487-0426.

For questions about your rights as a research subject, contact the Eastern Michigan University Human Subjects Review Committee at human.subjects@emich.edu or by phone at 734-487-3090.

Voluntary participation

Participation in this study is voluntary. You may refuse to participate at any time with no penalty, loss, course enrollment, or effect on grades. If you leave, your information will be kept confidential. You may send a written request that your identifiable information be destroyed, but we cannot destroy any information that has already been published.

Signatures

____

Name of Subject

____

Signature of SubjectDate

I have explained the research to the subject and answered all their questions. I will give a copy of the signed consent form to the subject.

____

Name of Person Obtaining Consent

____

Signature of Obtaining ConsentDate

Appendix G: Experiment 2

Experiment 2: Properties of Matter

Completion of this laboratory activity builds towards NGSS Performance Expectations 2-PS1-1: Plan and conduct an investigation to describe and classify different kinds of materials by their observable properties and 2-PS1-4: Construct an argument with evidence that some changes caused by heating or cooling can be reversed and some cannot.

Parts 1-4 were not relevant to this study

Part 4: Why do we need a better plastic?*

Instructions for activity: Read the following welcome letter from the Polymer Providers company and answer the corresponding questions.

Dear Student Scientists,

The *Premier Polymer Providers Company* makes many plastic products for our customers. Our customers include:

- **Commercial Airplanes**: Commercial airplanes use our plastics to make the stow bins on every airplane!
- **K2:** K2 uses our plastics for top sheets and wheels on skateboards and inline skates.
- **Nutcase:** Nutcase uses our plastics for the outer shell of their colorful and popular sports helmets.
- **Pocock Rowing:** Pocock Rowing makes the world’s best racing shells for crew and uses our plastics to make the fastest and lightest boats.

Lately, our customers have grown concerned about using our plastics. They say our plastics could be harmful to the environment.

Our customers have asked us to design a new kind of plastic. They are looking for a plastic that is less harmful to the environment. Some engineers suggested that we design a biopolymer. Biopolymers are similar to plastics, but they are less harmful to the environment.

We are turning to you for your help and ideas. We want you to engineer our next great line of biopolymers. We hope you will join our company and help us design a more sustainably minded polymer.

Sincerely,

The Premier Polymer Providers Company

*Activity adapted from *Polymers for the Planet (https://www.teachingchannel.org/polymers-engineering-unit-boeing*)

Premier Polymer Provider customers want to replace the current plastic products with biopolymers, as they are better for the environment. Why do you think the current plastic is harmful to the environment?

In order to better understand the problem, we need to look at reliable data sources. Read the two articles linked below and look for answers to the question *Why do we need better plastics?* Record your evidence.

http://www.scholastic.com/browse/article.jsp?id=3751739 https://www.nature.com/news/bottles-bags-ropes-and-toothbrushes-the-struggle-to-track-ocean-plastics-1.20432

Evidence from the Scholastic article about why we need better plastics:

Evidence from the Nature article about why we need better plastics:

Appendix H: Experiment 4

Experiment 4: Density

Completion of this laboratory activity builds towards NGSS Performance Expectation 5-PS1-3: Make observations and measurements to identify materials based on their properties.

Part 2: Why do plastic containers have those different numbers stamped on them?*

As you started to explore in Experiment 2, the world is in need of better plastics that are less harmful to the environment. Biopolymers, which are made of renewable materials and may decompose differently than petroleum-based plastics, could be a step in the right direction. In order to be adopted into use, any biopolymer or other new plastic type needs to have similar performance properties to existing petroleum-based plastics (while also being less harmful to the environment). In this activity, you will observe different types of petroleum-based plastics to identify their specific characteristics and properties. Plastics are generally divided into 7 main categories, each of which is given its own RIC (Resin Indicator Code).

Instructions: Visit each plastic station. Carefully observe each type of plastic. Record the color, texture, hardness, flexibility, and any other characteristics or properties you identify. Additional resources you may find useful: http://www-tc.pbs.org/strangedays/pdf/StrangeDaysSmartPlasticsGuide.pdf

https://www.compoundchem.com/wp-content/uploads/2015/04/Guide-to-Common-Plastics-RECYCLING-CODES.pdf

http://archive.theplastiki.com/assets/static/downloads/resin_codes_A4.jpg

http://archive.theplastiki.com/assets/static/plasticsissues/5gyres_full.jpg

http://archive.theplastiki.com/wp-content/uploads/2010/06/plastiki-_Plasticresincodes_RGB.jpg http://archive.theplastiki.com/assets/static/plasticsissues/plastictross_full.jpg

Polymer name:

At least three detailed observations about the properties and characteristics:

Common uses:

Comparison to other plastic types:

*Activity adapted from *Polymers for the Planet* https://www.teachingchannel.org/polymers-engineering-unit-boeing

Polymer name:

At least three detailed observations about the properties and characteristics:

Common uses:

Comparison to other plastics:

Polymer name:

At least three detailed observations about the properties and characteristics:

Common uses:

Comparison to other plastics:

Polymer name:

4 LDPE

At least three detailed observations about the properties and characteristics:

Common uses:

Comparison to other plastics:

5 PP

Polymer name:

5 PP

At least three detailed observations about the properties and characteristics:

Common uses:

Comparison to other plastics:

5
PP

Polymer name:

6
PS

At least three detailed observations about the properties and characteristics:

Common uses:

Comparison to other plastics:

Polymer name:

At least three detailed observations about the properties and characteristics:

Common uses:

Comparison to other plastics:

Part 3: How can we sort plastics if they aren't coded?*

"The Plastic Ocean" in Lab 2 introduced you to plastic pollution. In these activities, you will take a closer look at one type of plastic pollution that has been in the news recently: microplastics. These are plastic pieces that are less than five millimeters long, or around 0.2 inches (https://oceanservice.noaa.gov/facts/microplastics.html). Microplastics come from either larger plastics that were broken apart, or from commercial microbeads in toothpaste and face cleansers. Although the United States has banned the use of microbeads in personal care products, microplastics are still a major concern as they are consumed by wildlife and pollute aquatic habitats. Although labor intensive, plastics of all sizes can be removed from the environment. While recycling these plastics is an option, many fragments no longer have an RIC code. If only there was a property inherent to the material that we could easily measure...

Luckily for us, each RIC category has a different density (see the chart in Figure 1). A plastic fragment will sink in those liquids of lower density than its own, and it will float on those with higher density values. For example, we can confidently expect an object made of Plexiglas® (density = 1.24 g/mL) to sink in water (density = 1.00 g/mL), whereas one made of polypropylene (density = 0.91 g/mL) will float.

The reverse application is also useful: if a piece of plastic floats on pure water we know it can't be Plexiglas®.

Warning: Ethanol is a flammable liquid. Ethanol is harmful by ingestion, inhalation or skin absorption; it is an irritant of the eyes, nose, throat and skin.

Activity 1 instructions: Using tweezers, take one of the samples of plastic and carefully place it in solution 1. Gently shake the plastic in the solution to dislodge any trapped air. Observe if the sample sinks or floats in the liquid. This may take a minute. Record results in your observation table (see next page). Remove the sample from the solution, rinse it and the tweezers with water, then dry with a paper towel. Repeat this procedure with solution 2, then solution 3, etc. Using Figure 1, double check that the density of the solutions the known plastic sample sinks in are lower than the density of the plastic. Also check that the density of the solutions in which it floats are greater than its own density. Repeat this entire process for each known plastic sample.

Choose one unknown plastic sample and test it with the same process as the known plastics. Estimate the unknown's density as being between the densities of the last solution it sinks in and the first one in which it floats. Use this value to identify your unknown sample (see Figure 1).

*This activity is adapted from: "Floating Plastics: An Initial Chemistry Laboratory Experience" by Enrique A. Hughes, Helena Ceretti, and Anita Zalts.

	Solution 1 76.8% v/v ethanol	Solution 2 57.9% v/v ethanol	Solution 3 41.3% v/v ethanol	Solution 4 water	Solution 5 12% w/w NaCl	Solution 6 54% w/w sucrose	Solution 7 45% w/w K_2CO_3
1 PETE Polyethylene terephthalate							
2 HDPE High Density Polyethylene							
4 LDPE Low Density Polyethylene							
5 PP Polypropylene							

6 PS Polystyrene							
unknown plastic							

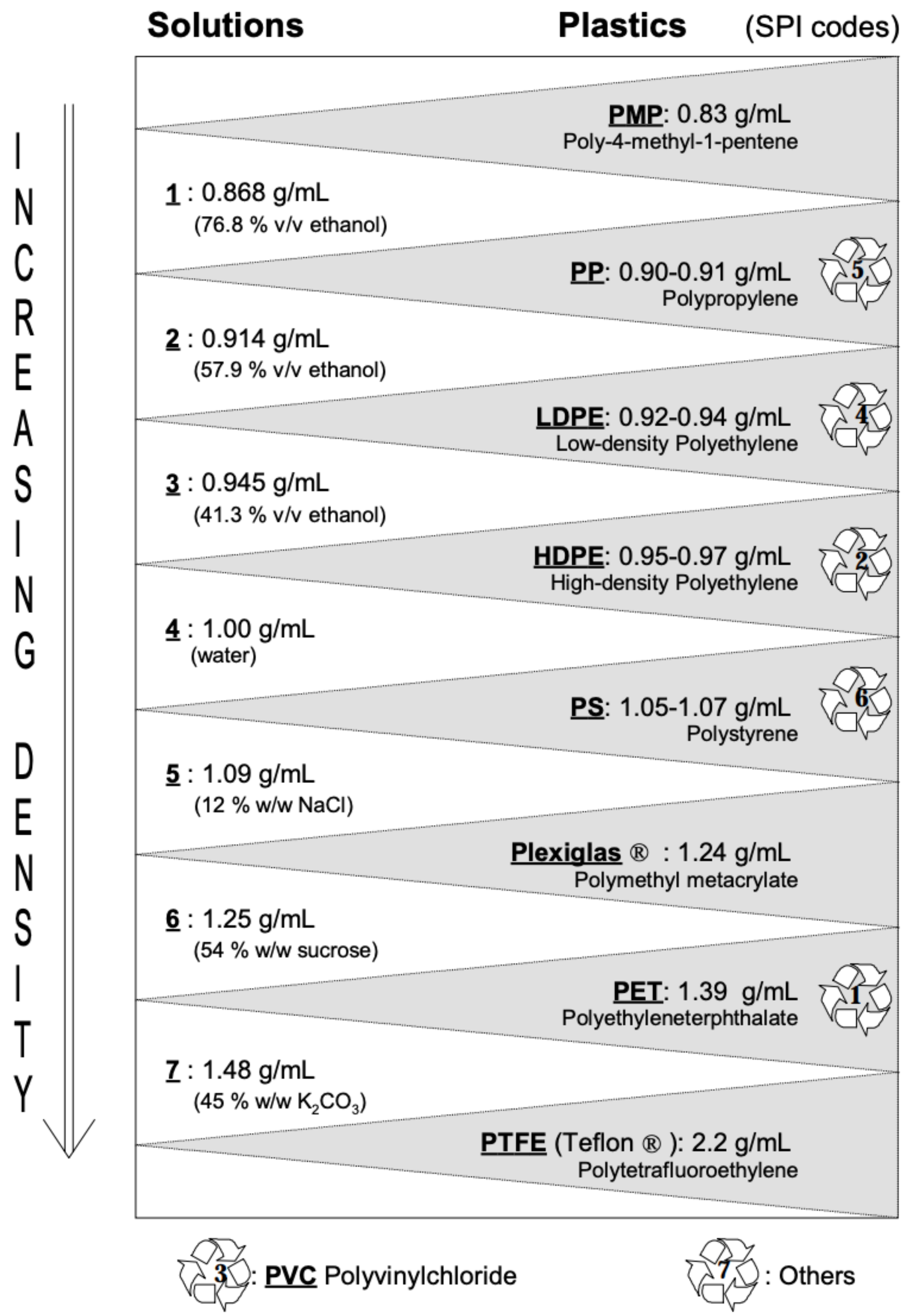

Figure 1. Densities of plastics and provided solutions.

Activity 2 instructions: Empty your microplastic mix into **solution 7**, the highest density solution. Gently stir the plastic in the solution for a minute to dislodge any trapped air. Wait several seconds to allow plastic pieces to either float or sink, as there are multiple pieces of multiple types of plastic in each sample. Note in your table if any of the plastics in your mix sink in the solution. Lift out all of the pieces that float with a spoon, rinse them with water, and dry them. Remove the ones that sank (if any) and set them aside. Place the pieces that **floated** in solution 7 into solution 6. Repeat the procedure, making your way from solution 7 to solution 1. The different plastic types in your mix will sink in different solutions, as you observed in Activity 1, so this process will separate the mix. Once all of the different plastic types have been separated, you can identify them using Figure 1 and your observations from Activity 1.

Microplastic mix number:_____________________

	Solution 1 76.8% v/v ethanol	Solution 2 57.9% v/v ethanol	Solution 3 41.3% v/v ethanol	Solution 4 Purified water	Solution 5 12% w/w NaCl	Solution 6 54% w/w sucrose	Solution 7 45% w/w K_2CO_3
What solutions did micro-plastics sink in? Indicate with a checkmark.							

Thinking about your data:

1. Use the CER framework to make a scientific argument for the identity of your unknown plastic sample from Activity 1.

Claim:

Evidence:

Reasoning:

2. Based on your observations, what plastic types (SPI codes) were present in your sample for Activity 2? Explain your answer.

3. How does experiencing a small bit of the challenges involved in separating unmarked plastics make you think about how you could do things differently in regards to plastic usage in your home or school? What changes could you implement?

Appendix I: Prep Day Activities

Prep Day Activities

Part 1: Water Pollution Clean-up Challenge*

You and your team will design a clean up system for a polluted body of water. Your goal is to clean your sample *using no more than two treatments* (see table below) and *return as much of the water as possible* to a *neutral, unpolluted state*. Just as practicing engineers do, you will need to consider the pros and cons of your clean up methods and work within the constraints provided. Once you have a plan, implement your design and assess its effectiveness. When all teams have collected their data, you'll share the results with your fellow engineers and revise your method based on the new data.

Treatment Name	Description	Cost	Time
Chemical removal (Baking soda)	React the contaminant with a reagent to make it less toxic.	$$$	Fast
Absorption (Cotton balls)	Use an absorbent barrier or material to treat the spill.	$	Moderate
Filtration (Coffee filters)	Use filter media to separate contaminants from water.	$$$$$	Moderate
Collection (Plastic spoons)	Physically remove contaminants using a method of collection.	$	Slow
Surfactant (Dish soap)	Use soap or other reagent to break down oils in water.	$$$	Fast

Write a detailed procedure for your team's clean-up plan. How did your team decide which treatments to use?

*Procedures modified from http://www.discovere.org/dreambig/activities/db-activity/Water%20Pollution%20Cleanup and https://www.teachengineering.org/activities/view/cub_enveng_lesson01_activity1 and "Floating Plastics: An Initial Chemistry Laboratory Experience" by Enrique A. Hughes, Helena Ceretti, and Anita Zalts.

Collect data that allow you to assess the effectiveness of your plan against the stated criteria. Neatly record your data in the space below. Write a brief analysis of your findings to share with the other teams, including answers and explanations to the questions: Is your water sample potable (safe)? Is your water sample palatable (looks and smells good)?

Based on what you learned from the other teams, revise your original plan in the space below, using the smallest number of treatment plans as necessary to make the water sample *both potable and palatable*. Implement your revised design. Are the results better, worse, or the same as your first trial? Record your data and compare your first and second trial results. Write a brief analysis of your findings.

Part of the pollution you removed from your water sample was microplastics. While you may want to recycle this waste, the pieces do not contain the SPI codes to allow you to know if the plastic is recyclable. Your team will need to identify the types of plastic found in your contaminated water sample by doing a density test.

Empty your microplastics removed from the contaminated water into **solution 5**, the highest density solution. Gently stir the plastic in the solution for a minute to dislodge any trapped air. Wait several seconds to allow plastic pieces to either float or sink, as there are multiple pieces of multiple types of plastic in each sample. Note in your table if any of the plastics in your mix sink in the solution. Remove all of the pieces that float, rinse them with water, and dry them. Remove the ones that sank (if any) and set them aside. Place the pieces that **floated** in solution 5 into solution 4. Repeat this same procedure with solution 1. The different plastic types in your mix will sink in different solutions, so this process will separate the mix. Once all of the different plastic types have been separated, you can identify them using the information in Figure 1 (next page).

	Solution 1 76.8% v/v ethanol	Solution 4 Purified water	Solution 5 12% w/w NaCl
What solutions did micro-plastics sink in? Indicate with a checkmark.			

What types of plastics could be present in your contaminated water sample? How do you know?

How does experiencing a small bit of the challenges involved in cleaning polluted water and separating unmarked plastics make you think about how you could do things differently in regards to plastic usage in your home or school?

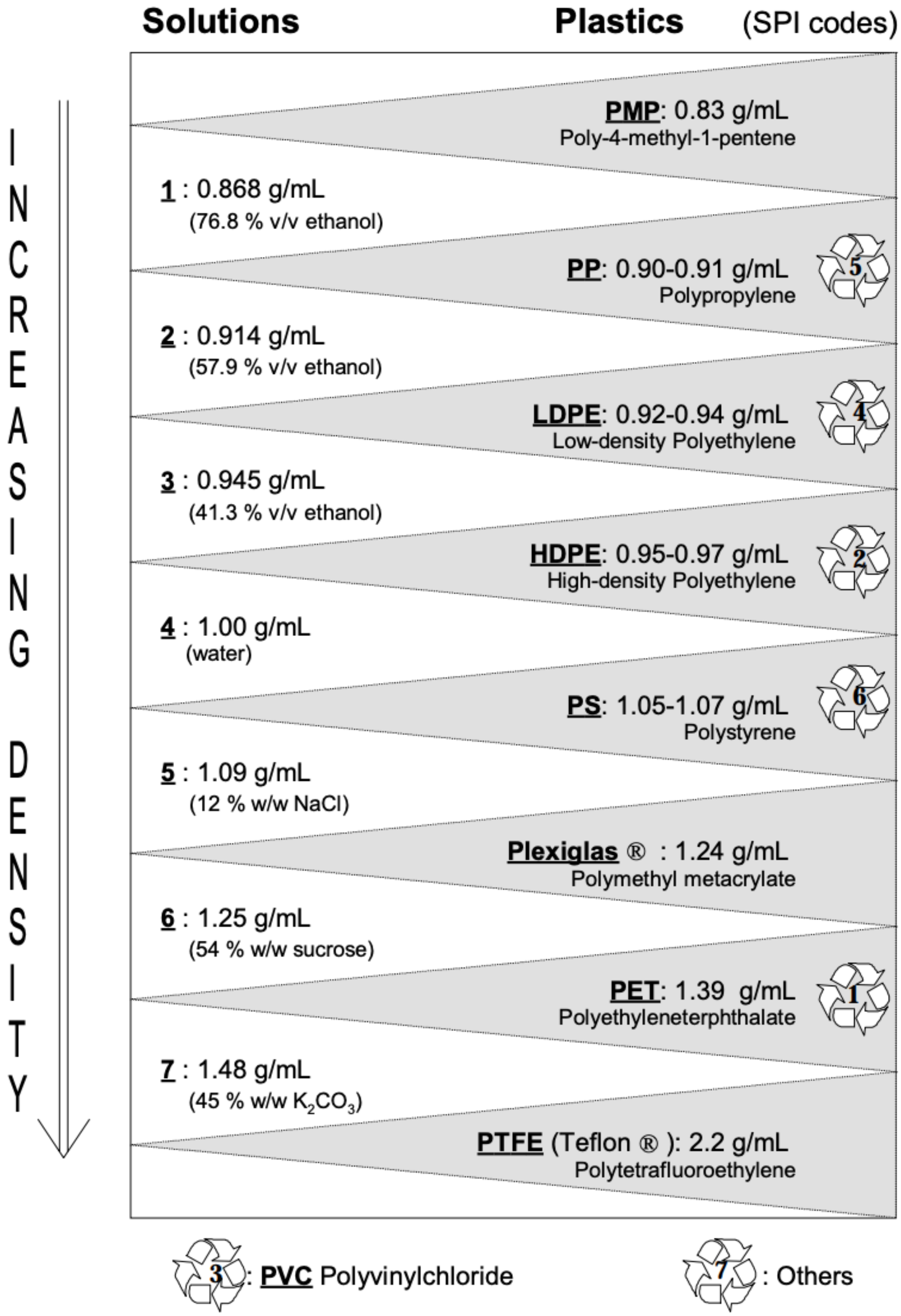

Figure 1. Densities of plastics and provided solutions.

Activity 2: How long until it's gone?*

Rivers, lakes, and oceans are increasingly becoming polluted with a variety of plastics and other human-produced garbage. Such pollution poses a threat to the health and safety of the wildlife that live in and near these waters through entanglement, ingestion, and/or disruption of habitat and reproduction.

Review the common types of marine debris provided for you. As a team, discuss how long you think each type of material takes to decompose and place it at the appropriate spot along the timeline at your station. Discuss why you think each type of debris takes a particular amount of time to decompose. Record your timeline and reasoning in the space below.

List as many ways as you can think of that marine debris can make it into waterways.

*Procedure modified from https://www.coastal.ca.gov/publiced/directory/personal_trash_ choices.html and https://oregoncoaststem.oregonstate.edu/sites/ oregoncoaststem.oregonstate.edu/files/MD/smile3-howlong.pdf

Discuss the actual rates of decomposition of these materials with Dr Johnson, Mary, or Tori. Afterwards, discuss with your group if knowing how long these materials take to decompose is important for people to know. Do you think that everyone's actions have an impact (both positive and negative) on the environment? Why or why not? Record your thoughts below.

Take a look at the examples of objects you may encounter in your daily lives. With your team, sort these objects into four categories:

- Reduce (you will reduce the occurence of the item because you do not buy or use it)
- Reuse (you will buy it and reuse it somehow)
- Recycle (you will recycle the item when you are done with it)
- Trash (you will throw the item away in the trash when you are done with it)

In the space below, explain why you sorted the objects into the categories that you did. Does knowing how long these items take to decompose influence your decisions about how to categorize the items?

Look back at the various examples of plastics you've examined in this activity. We tend to think about plastic as one type of thing, but do all plastics have the same properties? Place the plastics from this activity into groups by similar properties and explain how the groups are alike and different. What kinds of things would your groups of similar plastics be good for and what kinds of applications would they NOT be good for? How is this activity like what scientists do?

Use your creativity to express how your choices as an individual can impact the environment. Draw a picture, make a poster, write a poem, etc. to share your thoughts and feelings with your friends and family.

Appendix J: Experiment 6

Experiment 6: Chemical Reactions

Completion of this laboratory activity builds towards NGSS Performance Expectation 5-PS1-4: Conduct an investigation to determine whether the mixing of two or more substances results in new substances.

Part 3: What kind of biopolymer do you want to make?

Select your starch (potato, corn, arrowroot), plasticizer (formula A or B), and amount of glue additive (between 1 to 5 tsp) on the sign-up sheet. Label your weighing boats with your name, and specify which one is your biopolymer with additive.

Put all ingredients in a clean 400 ml beaker

Plasticizer A	100 mL water & 10 mL pure glycerin or glycerol
Plasticizer B	80 ml glycerol solution, 5 ml salt water solution
Starches	If you used Plasticizer A: 10 g If you used Plasticizer B: 3 g
Food coloring	As many drops as needed to achieve desired color

For the biopolymer with additive: put all ingredients in a clean 400 ml beaker

Plasticizer A	100 mL water & 10 mL pure glycerin or glycerol
Plasticizer B	80 ml glycerol solution, 5 ml salt water solution
Starches	If you used Plasticizer A: 10 g If you used Plasticizer B: 3 g
Additives	Write the amount of additive you decided on here.
Food coloring	As many drops as needed to achieve desired color (pick a different color than your original biopolymer

Turn the hotplate to high and set the beakers on the hot plate. For plasticizer A, set the hotplate to 220-230 degrees. For plasticizer B, set your hotplate to 320-330 degrees. Stir the materials **continuously** with a glass stir rod as they begin to gel and get sticky. Continue to heat until the mixtures boil. If your mixture doesn't boil after 10 minutes, set your stir rod in the beaker. After a minute or so, you should see **small** bubbles form around the bottom of the stir rod. This indicates your mixture is boiling, but is too viscous for the bubbles to rise to the top easily. Then allow it to heat for another minute. Using your rubber mitt since the beakers will be HOT!, pour the mixture into the weighing boat.

Immediately after pouring your mixture into the mold, make observations of *both biopolymers* in the space provided below. What differences do you see between your samples with and without an additive?

Talk with other groups who used a different starch and/or plasticizer and/or amount of additive. How are their observations similar to and different from yours?

An NGSS K-2 DCI for PS1.A: Structure and Properties of Matter states “Different properties are suited to different purposes.” Using your observations, those from other groups, as well as the demo samples Tori prepared, how does this activity illustrate the main concept of the DCI?

Part 3: What properties do your biopolymers have?

Instructions for activity: Carefully remove your biopolymers from their containers, making sure to know which is which. Record the materials you used to make your polymers in the table below. In addition, write observations of your polymer in the space provided below. Does it stretch, bend, or fold? Is the sample uniform, or does it have defects like bubbles or cracks? What else do you notice? You can even draw a picture. What plastic or polymer does it remind you of and why?

Biopolymer recipe

Starch	Plasticizer	Additive

<u>Polymer Observations Polymer with additive Observations</u>

Biopolymer stretch test:

Cut three samples of each polymer, about 2 cm x 8 cm. For the first sample, record the initial length. Hold the short edge of the sample flat to the surface of the table. Set the ruler along the polymer sample so its edge is at zero. While applying pressure to the edge of the polymer, pinch the free edge. *Slowly* and *steadily* pull the free edge. Have your partner observe the sample as it stretches. Once the sample breaks, record the final length. If your sample doesn't stretch, write observations about its malleability (can it move at all) and rigidity in the table instead. Repeat this test procedure for the rest of the polymer and polymer with additive samples. Then calculate the percent elongation of the samples and enter the values in the tables below. Average the percentages of elongation for each polymer.

Percent elongation =

Biopolymer stretch test

Trial	Initial Sample Length (cm)	Final Sample Length (cm)	Percent Elongation %

Biopolymer with additive stretch test

Trial	Initial Sample Length (cm)	Final Sample Length (cm)	Percent Elongation %

Average percent elongation for the polymer	Average percent elongation for the polymer and additive

Thinking about your data: Describe how your polymers performed in the elongation tests. What differences did you observe between your polymer and your polymer with additive?

Based on the properties you observed, what product do you think you could make from your polymer (e.g., tupperware, fishing line, etc.)? Explain.

Look at your classmates' polymers and elongation test data. How do the different starches and plasticizers affect polymer properties?

An NGSS K-2 DCI for PS1.A: Structure and Properties of Matter states “different properties are suited to different purposes” while an NGSS 3-5 DCI for PS1.B: Chemical Reactions states “when two or more different substances are mixed, a new substance with different properties may be formed.”

Using your observations of your final product, those from other groups, and the styrofoam alternative you made, how do these environmentally focused activities illustrate the main concept of the disciplinary core ideas listed above?

Appendix K: Biopolymer Sign-Up Sheet

Biopolymer Sign Up Sheet (some of these will repeat)

Names	Plasticizer	Starch	Amount of additive Between 1-5 tsp
	A	Potato Starch	
	A	Arrowroot	
	A	Corn Starch	
	B	Potato Starch	
	B	Arrowroot	

	B	Corn Starch	
	A	Arrowroot	
	A	Corn Starch	
	B	Corn Starch	

Appendix L: Pre/Post Survey

Pre/post Survey for CHEM 101

1. Describe in your own terms what a polymer is.

2. What polymers do you use in your day-to-day life?

3. How often do you recycle these materials? Circle the option that best describes your answer.

    a. Plastic containers/bottles

Almost never	About 25% of the time	About 50% of the time	About 75% of the time	Nearly always

Paper

Almost never	About 25% of the time	About 50% of the time	About 75% of the time	Nearly always

Aluminum cans

Almost never	About 25% of the time	About 50% of the time	About 75% of the time	Nearly always

Explain why in the space provided below.

4. To what extent do you believe plastic pollution to be a problem? Circle the answer that best describes your answer.

Plastic pollution is not a major problem	Plastic pollution is an issue, but is not a major environmental concern	Plastic pollution is a significant environmental concern	Plastic pollution is a major environmental concern and requires immediate intervention

Explain why in the space provided below.

Appendix M: Post-Laboratory Survey

Weekly Post-Laboratory Survey

1. Name and explain at least two things that went well in the laboratory today

2. Name and explain at least two things in the laboratory today that can be improved to create a better experience?

3. What material in this module was the most significant to you? Explain.

4. How do you foresee using the material from this unit in your future classroom? If you do not, explain why.

Appendix N: Focus Group Interview Questions

Focus Group Interview

1. Which laboratory did you find the most interesting and why?

2. What changes would you make to the laboratory curriculum before teaching this material again?

3. What is your relationship with disposable plastic going to look like going forward?

4. How do you feel about teaching this material in your own classrooms?

Follow up questions:

How do you feel about teaching this material to the fifth graders coming in?

Anything to add?