Deriving Solutions to Reduce Waste in Introductory Biology and Chemistry Teaching Laboratories at WPI

An Interactive Qualifying Project
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Abstract

Laboratory courses will, by their nature, produce some amount of waste. With the goal of reducing the amount of waste in WPI's introductory biology and chemistry teaching labs, we assessed both the nature of the waste produced and procurement of lab supplies. We did this by interviewing personnel from relevant departments, surveying students and faculty involved in labs, observing lab course sections, and analyzing purchasing data acquired from lab management offices. Our suggestions for changes include standardized material categories for digital inventory records, enhanced waste disposal posters, utilization of recycling programs, and increased lab instruction.

Acknowledgments

We would like to thank our advisors, Professor Amity Manning and Professor Paul Mathisen for their guidance and patience with us for our Interactive Qualifying Project. Professor Manning's background with graduate laboratories regarding her teaching lab in Gateway Park at WPI, brought insight into laboratories outside our project and allowed us to make conscious decisions based off her knowledge and perspective. Professor's Mathisen's work with WPI's Office of Sustainability allowed us to understand how sustainability works at WPI and assess what solutions are still a work in progress. Our advisors were also extremely helpful regarding our questions and concerns and getting in contact with other people at WPI.

We would also like to thank the director of WPI's Environmental Health and Safety Office, Daniel Sarachick, and the custodial staff at WPI, for their insight on this project. Understanding how waste is handled at WPI would not have been possible without their responses.

We would also like to thank Laurie Colella, Michael Brunelle, and their team at WPI's Procurement Office for their insight into this project. Without their help, understanding the purchasing system for undergraduate laboratory courses would not have been achievable.

Finally, we would like to thank the faculty of WPI's chemistry and biology departments for their assistance with this project. This specifically includes biology lab manager Mihail Bocka, chemistry lab manager Paula Moravek, biology professors Jill Rulfs and Mike Buckholt, and all the chemistry lab instructors we contacted. Without their interview responses, consent to observe their laboratory courses, and access to their purchasing data, the quality of understanding waste disposal at WPI would not be feasible.

Executive Summary

Please note that this project contains a lot of technical terms. As a result, we have included a glossary in Appendix A. Clickable words, besides Appendix Items, will link to their corresponding glossary entry.

Background

Laboratories can produce high volumes of waste, much of which has detrimental effects on the environment. This high amount of waste is a natural byproduct of lab work. As lab workers perform their experiments, they amass a plethora of substances they no longer need. This could be for reasons like the substances becoming contaminated or chemically altered. Here, the lab worker will likely consider most of these substances waste, and promptly dispose of them.

Most lab waste can be broken into two categories: material and chemical waste. Chemical waste refers to leftover chemical substances from experiments, while material waste refers to all other trash generated during these experiments. For example, a reagent would be chemical waste and gloves would be material waste.

Material waste items are typically made of either plastic or glass. Plastic items are disposed of either by incinerating them or sending them to a landfill (National Research Council, 1989). Incinerating plastic is detrimental, as this process can release toxic gases into the atmosphere (Wirsig, 2022). Landfilling plastic is no better, as the plastic can leach harmful chemicals into the surrounding soil (Teuten et al., 2019). Glass is also commonly disposed of in landfills, where its inert properties make it difficult to break down (Kellogg, 2019). This fact means glass takes up space in landfills indefinitely, which is problematic considering all landfills in the United States are quickly approaching full capacity (Thompson & Watson, 2018).

Chemical waste can be classified as either hazardous or non-hazardous. Hazardous chemical waste contains substances that are highly reactive or toxic (United States Environmental Protection Agency, 2015a), while non-hazardous chemical waste does not. Like material waste, all forms of chemical waste can cause harm during their disposal. Non-hazardous chemical waste is disposed of either by pouring it down the drain or sending it to a landfill (Chen et al., 2020; Stanford Environmental Health & Safety, n.d.). Landfilling this waste contributes to the problem of our dwindling landfill space, while sending the waste down the drain funnels it into treatment facilities whose operation releases greenhouse gases (Express Clear Solutions, 2019; Zawartka et al., 2020). Hazardous chemical waste undergoes a much more rigorous disposal procedure than this non-hazardous waste. This waste must be treated to remove its dangerous properties (Varshney et al., 2022), but this treatment process can cause significant environmental harm. For example, the waste may be treated via incineration, which releases toxic chemicals into the air (Domingo et al., 2020).

Over the past decade, many people have begun to realize the negative impacts of lab waste (Relph, 2020). There are now hundreds of individuals and groups developing solutions to reduce this waste, or limit its effects (Relph, 2020). These solutions can be broadly broken up into three categories: procedural, physical, and behavioral solutions. Table 1 gives an overview of these solutions with some examples.

Table 1. Examples of solutions to reduce lab waste, and its negative effects.

Solution Type	Definition	Example
Procedural Solutions	Solutions that change the experiments and practices of the lab	Scale down experiments to make them use less materials and chemicals
Physical Solutions	Solutions that involve acquiring new equipment or items for the lab	Purchase materials and chemicals that have a less negative environmental impact
Behavioral Solutions	Solutions that involve changing the conduct of the lab's workers	Give lab workers greater training in waste reduction

Goal

In our project, we aimed to look at lab waste in the context of the introductory chemistry and biology teaching labs at Worcester Polytechnic Institute (WPI). We planned to assess the amount of material and chemical waste generated in these labs, and the major factors contributing to this waste. With this knowledge, we aimed to derive practical solutions to reduce this waste and its negative impacts. We also investigated ways to make the waste generated by these labs more easily trackable to aid future waste reduction endeavors. We hope our solutions will help foster a greater culture of sustainability in WPI's teaching labs and lower the environmental harm caused by the university.

Methodology

In order to achieve these goals, we developed the following research objectives:

1. Quantify the amount of plastic, glass, and nitrile glove waste generated in undergraduate chemistry and biology labs.
2. Investigate what changes can be made to WPI's lab material purchasing system so that waste types and amounts can be tracked and managed better.
3. Investigate the causes and solutions to excess waste generation and improper waste disposal from both a WPI administration and student perspective.

In a laboratory setting, experiments are conducted in a way that controls variables. As a result, certain materials used in experiments are often disposed of rather than reused. Our project is focusing on waste generation, so these disposable lab materials were of great interest to us. We chose to analyze the number of disposable materials that were purchased, assuming that they would be thrown out. So, if the labs buy 1,000 pipettes a month, it can be assumed that the labs will be throwing away 1,000 pipettes a month. We contacted the Goddard Hall biology lab manager, Professor Jull Rulfs, for all the purchases carried out by the biology teaching labs that are still on record. We also contacted the chemistry lab manager, Paula Moravek, for the chemistry teaching labs purchases. We analyzed this raw data according to Appendix B. An important thing to note is that we translated the *amount* of each item into the *weight* of each item. This allows us to make fair comparisons between smaller items and bigger ones.

While analyzing the purchasing system data, we noticed several limitations that hindered our investigation. We want to make sure the purchasing system can be used for later sustainability investigations, either by WPI administration or future IQPs. Therefore, we start ed searching for ways to alter the purchasing system for future sustainability use.

Unfortunately, WPI does not make all its purchases through the same system. When a purchase is made outside of WPI's preferred vendors, purchasers must use something called a P-Card, which is in essence a company credit card from WPI. When a P-Card purchase is made, information about the item is *not* recorded. **Therefore, we were not able to analyze P-Card purchases at all.** With this information, we interviewed WPI's Procurement Office (which manages WPI's purchasing system) about potential changes to the system. Our questions to Procurement are in Appendix D.

Additionally, we wanted to know how students were performing in lab. Students who make several errors and are confused about the lab procedure will create excess waste. Students can also dispose of waste improperly, which can lead to environmental harm. To get a sense of these issues, we surveyed students using Qualtrics. Before the creation of the survey, we drafted solutions we believed would help curb excess waste generation and improper waste disposal (which can be found in Section 3.3.1). The student survey, located in Appendix E, asked several different categories of questions. A full breakdown of the survey is in Section 3.3.2, but in essence, it asked about how often students make mistakes in lab and how they felt about our drafted solutions. If students favored our solutions, then we could argue to implement them. We emailed students a link to the survey. In order to increase the number of responses we would receive, students who completed the survey were entered into a raffle to win a $25 Amazon gift card. We also created a professor/TA survey (Appendix F) which asked similar questions, but we were not able to distribute it via email, so we received too few responses. The full procedure of student and professor/TA survey distribution can be found in Appendix G. The figures we generated from the student survey data are in Appendix H.

To put the surveys and proposed solutions in context, we observed 13 chemistry and biology in-person lab classes. We contacted the professors teaching these lab courses and asked if we could observe them. Before observing the classes, we looked at the procedure students would be following for that experiment. If a student veered away from the established procedure in a way that would produce more waste, we would record that observation. It is important to note that we did not want to know how much students were using (as that should be covered by the purchasing data), but rather what were the *causes* of excess waste and improper waste disposal. Our observation procedure for these classes can be found in Appendix J. To get an idea of what happens to the waste students generate in lab, we also interviewed WPI's Office of Environmental Health and Safety (EHS), which deals with the disposal of lab waste. Our questions for EHS are in Appendix I.

Findings

This section details our investigation of the current waste management system and evaluation of the state of sustainable practices in introductory biology and chemistry labs. Evidence from our surveys and interviews was used to identify limitations in the sourcing and disposal operations for laboratory materials. Surveys conducted gave us an insight on the current culture of sustainability in WPI introductory labs and identified areas where we can implement green lab principles into our work and research.

We administered a survey to assess student opinion on plastic, glass, and chemical use and conservation practices in chemistry and biology introductory lab classes. We collected 1,069 responses from students who have taken introductory chemistry and biology lab classes at WPI. The following criteria filtered these responses if completion of the survey is greater than 90%, the initial question of have you taken an in-person introductory biology and/or chemistry lab at WPI is answered yes, and the response type is not "survey preview, survey test, spam, survey preview spam, spam, imported spam, EX spam", leaving us with 902 responses that were analyzed.

The student survey shows that students at WPI acknowledge the environmental impact of laboratories and support sustainable practices in labs. It also indicates that a significant portion of students were frequently confused on how to dispose of waste in introductory chemistry labs, that most students are in favor of having waste disposal posters, that a significant portion of students did not fully understand the procedures when performing experiments in their introductory chemistry labs, and that WPI students are open to changes aimed at reducing the environmental impact of their introductory biology and chemistry labs.

Instructor and teaching assistant (TA) surveys were distributed in hopes to gain a different perspective on sustainable practices in introductory biology and chemistry labs. The instructor and TA survey only received three completed responses, with one including a response from an undergraduate chemistry TA. Consequently, analysis would likely not be representative of the perspectives of instructors and teaching assistants in biology and chemistry introductory labs.

We conducted interviews to further investigate the nature of lab management and supply procurement. Through interviews with various departments, it was determined that the compartmentalized structure of the departments, as well as the lack of an effective network above them to facilitate communication between them, impact the overall clarity of the purchasing systems in place. Independent budgets for each department allow for flexibility in purchasing consumables in response to class need and student demand. However, this same independence imposes limitations on how sustainability is approached, including stronger guidelines on what supplies are acquired and by what means they could be employed at the university level. This observation alongside the lack of standardized categories to sort items limits the ability to efficiently gauge the nature of the supplies possessed by lab departments. Consequently, this highlights the opportunity for aspects of the purchasing system currently in place to be modified to better assess and implement measures for increasing sustainability moving forward.

To better understand and gain an independent assessment of how undergraduate laboratory classes handle proper waste disposal, waste reduction, and incorporating these into the curriculum, we conducted laboratory observations for the following courses: CH1010, CH1020, and BB2915. While observing these course sections, we noted that there were not many waste disposal posters in the laboratories. Waste disposal posters that we found in labs were vague in their descriptions. We also found that there was little to no instruction regarding waste reduction or proper waste disposal. Based on our observation, students had a greater knowledge of proper waste disposal than waste reduction. Even still, students were observed dumping waste down the sink, placing chemical waste in the wrong disposal bin, breaking glassware and spilling chemicals. At times, students also appeared unsure how to assess the situation, frequently asking the professor or TA where the waste should be disposed of, and how to properly clean glassware containing the chemicals used in the experiment. unsure how to assess the situation, frequently asking the professor or TA where the waste should be disposed of, and how to properly clean glassware containing the chemicals used in the experiment.

In order to assess the amount of waste produced in undergraduate teaching labs, we obtained purchasing records for both the chemistry and biology departments. This data represents Goddard Hall's teaching labs. They were pulled from Workday and STARS purchases. The data is mostly focused on and represents all plasticware and glassware purchased through the procurement system for the use of the departments' teaching labs, specifically for the academic years between 2019-2022. The largest category of items in the chemistry purchasing history that was reviewed was Pasteur pipettes, with 16,560 purchased in one academic year. Dram vials were second to that with 10,440 item totals in that year.

It is important for any limitations in our assessment to be minimized for the solutions to be most effective. To accomplish this, we needed to gain more insight into how the procurement system works. This is the case for both the goal of mitigating the environmental impact of labs and the goal of making them more environmentally and financially sustainable. Through interviews with both the procurement offices and lab management and our preview of the procurement software, we found that aspects of the current purchasing systems' structure limit how efficiently a broader scope of understanding can be attained. This includes a lack of standardized categories to list inventory under in records, the level of detail and contributions from relevant personnel when seeking out information, and a lack of communication between departments.

Due to the limitations in the methodology and nature of information collected through the surveys and interviews, we didn't receive as much information from as many respondents as we potentially could have. However, what information we were able to acquire is sufficient to suggest changes to WPI's systems that would aid future projects like this one.

Conclusions & Recommendations

The project aims to embed a culture of sustainability within WPI laboratories to reduce the environmental impact of our research and education. Our objective is to develop solutions that will decrease the consumption of single-use plastic, single-use glass, and other lab commodities generated within WPI's instructional labs without adversely affecting operations. We hope to assess the amount of material waste generated in these labs, and the major factors contributing to this waste. We proposed solutions to help foster sustainable practices in labs and reduce our environmental footprint.

As some of these recommendations are on an administrative level, successfully implementing them depends on the degree to which the relevant departments within WPI's administration permit them. The extent to which the output of waste gets diminished relies on the efficacy of the solutions in practice and their capacity to be implemented. For solutions to apply in a lab setting, suggestions we have outlined include programs for recycling non-biohazardous nitrile gloves and glass, posters indicating what can and cannot be disposed of at specific locations in the lab, tutorials for experiments, and instruction on waste reduction.

We suggest using a program such as Zero Waste Boxes, a product by the company Terracycle. The boxes are receptacles filled with some specific waste and shipped back to the company, which processes and recycles the contents (TerraCycle, n.d.). A medium-sized bin from Terracycle would cost $283 but would be large enough to contain approximately 80% of the nitrile gloves that Goddard Hall purchases annually on average.

Glass waste is currently disposed of by incineration or in a landfill. The solution addressing glass waste is similar to the solution concerning nitrile gloves, in which non-hazardous glass waste can be recycled. The glass waste produced in teaching labs can be redirected from the current waste stream to a glass recycling facility.

We also recommend creating waste disposal posters for the introductory biology and chemistry lab rooms. These posters would give an overview of where each lab's waste products should be disposed of. The concise posters would be hung up in the respective lab rooms and placed in areas where students can easily see them. We specifically recommend that each introductory lab room have at least one poster that says where all the general types of waste produced in that room should be disposed of. Each type of lab waste has a specific waste stream it must go down. Improper waste disposal causes a waste item to enter the wrong stream, which can potentially lead to harm and compromise the proper disposal of waste with which it is commingled. These posters aim to reduce the frequency of improper waste disposal in the introductory biology and chemistry labs.

We recommend tutorials for experiments, which would involve creating videos to demonstrate how to perform the general techniques employed in some experiments. These videos would be implemented in lab classes that do not have instructional videos and they would be produced by the lab instructors to ensure an accurate demonstration of the lab. The tutorials would give students an idea of the general techniques they should implement and demonstrate safe methods of disposing of material lab waste. Instruction on waste reduction in the lab would involve significant emphasis on waste reduction in WPI's introductory chemistry and biology labs. The waste reduction instruction can provide general tips on how students can reduce waste throughout the course, detail when it is appropriate to reuse items in the lab, and how to dispose of non-hazardous and hazardous waste properly.

The purchasing system contains purchasing information on inventory, such as the quantity of items for each purchase, the price, and the catalog number of every item purchased. However, the purchasing system does not collect information that will allow items to be searched by specific criteria. Practical changes can be implemented to the structure of the purchasing system that will collect information in an assessable form. To account for the intake of laboratory materials, there is an opportunity to identify the classifying information at the stage of purchasing. Since WPI does not have a team focused on laboratory sustainability, we recommend establishing a separate team dedicated to sustainability of labs on campus and encourage collaboration between the Office of Sustainability and the Procurement Office. Although the purchasing system is structured for financial and budgeting purposes, implementing these changes will make the purchasing system more informative for WPI faculty and student projects such as this Green Labs IQP project.

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1. Introduction

Please note that this project contains a lot of technical terms. As a result, we have included a glossary in Appendix A. Clickable words, besides Appendix Jtems, will link to their corresponding glossary entry.

1.1 The Issue of Lab Waste

Labs can be energy and resource intensive by their nature. Safely conducting scientific research can require ventilation, temperature control, and sterility. The sourcing and disposal of laboratory consumables also has an environmental footprint. The Green Labs project aims to reduce the environmental impact of laboratories at Worcester Polytechnic Institute by assessing the contributing factors of laboratory waste and fostering a culture of sustainability that embraces WPI's innovative practices. This project provides solutions based on the amount of single-use plastics, single-use glass, and other lab commodities generated within WPI's instructional labs for the academic years between 2019 to 2022. Systems that have direct relations to these labs were also identified to develop feasible solutions and gain insight into the waste management and procurement process of undergraduate labs on campus.

A study from the University of Exeter estimated that biological, medical, and agricultural research produces about 5.5 million tons (about 6.1 US tons) of lab plastic waste per year and amounts to nearly 2% of global plastic waste (Urbina et al., 2015) Single-use plastics are a significant source of consumption and contribute to environmental pollution. Consumers benefit from plastic materials' cost-efficient, convenient, and sterile properties. These advantages of using single-use plastics have led to a reliance on disposable products within many laboratories. Although, plastic and other lab commodities should not be the only focus in reducing laboratory waste, with laboratories consuming ten times more energy and four times more water than a commercial office space (Paradise, 2019).

1.2 Gaps in Our Understanding of Lab Waste

According to RCRA (Resource and Conservation Recovery Act) and the United States EPA, Scientific Research and Development Service companies reported the disposal of 26 million pounds (about 11 million kilograms) of chemical and hazardous waste in 2019. The data published revealed that colleges and universities were responsible for an additional 16 million pounds (about 7 million kilograms) of chemical and hazardous waste. Although, even with the incentive for significant change, "there is still a misconception that incorporating sustainability into lab work is going to come at the cost of scientific integrity," said Rachael Relph, chief sustainability officer at My Green Lab, an organization dedicated to building a culture of sustainability in science (My Green Lab, n.d.). A shift in how research is conducted and supported is necessary to help reduce our environmental impact on campus. Undergraduate students in Biology and Chemistry labs may repeat experiments while producing excess waste or improperly disposing of laboratory waste. Providing alternatives, acknowledging sources of emissions, and spreading awareness of the environmental impacts of a lab can promote green lab practices.

Some sustainable options are not feasible in a lab, as certain research and curriculum demand specific equipment or methods that require abundant resources. The current labs and purchasing system may not have been designed with sustainability in mind. The project strives beyond mere adjustments to existing systems, fundamentally changing how we conduct research and education. To reduce material waste in WPI's labs, it is crucial to know the amount of material waste consumed and the type of materials entering the labs on campus. At the stage of purchasing, laboratory items can be identified and accounted for to estimate the amount of laboratory consumables and instruments. The organization of purchasing records and inventory, sufficient survey responses, and transparent resources available to the public are factors that were taken into account when deriving recommendations and solutions. This project evaluated the current waste management and purchasing system to determine possible refinements that will make information accessible to the WPI community.

1.3 Goal Statement

The project will support sustainability efforts at WPI by providing a comprehensive overview of the amount of material waste generated in undergraduate Biology and Chemistry instructional labs and provide practical solutions to reduce laboratory waste based on the data evaluated. Single-use materials are a significant source of consumption and contribute to environmental pollution. Our objective is to develop solutions that will decrease the consumption of single-use plastic, single-use glass, and other lab commodities generated within WPI's instructional labs without adversely affecting operations. We also hope to assess the contributing factors of laboratory waste and promote sustainable practices in laboratories on campus. The project aims to embed a culture of sustainability within Worcester Polytechnic Institute laboratories to reduce the environmental impact of our research and education.

2. Background

In this section, we begin by defining what lab waste is, the forms it can take, and the consequences of each of these forms. Next, we give an overview on the growing movement to diminish the negative impacts of lab waste, as well as the general strategies this this movement employs. Finally, we look at waste specifically in the context of teaching labs and examine a collection of specific solutions to reduce its quantity and ecological impact.

2.1 Defining Lab Waste

The United Nations defines waste as items the owners of which no longer desire, and instead wish to dispose of (United Nations Statistics Division, 2013). Waste is a natural byproduct of lab work. As lab workers perform their experiments, they amass a plethora of substances they no longer have any direct uses for. This could be for reasons like the substances becoming contaminated or chemically altered. Here, the worker will likely consider most of these substances waste, and promptly dispose of them.

Most lab waste can be classified as either material or chemical waste. Material waste refers to items made plastic, glass, or related items whose former purpose involved the containment, protection, or transfer of substances. Examples of material waste include used pipette tips, vials, and gloves. Looking next at chemical waste, this term refers to leftover chemical substances from lab procedures, or unwanted excess of these substances. Examples of chemical waste includes solvents, reagents, and cleaning solutions. Both chemical and material waste can come in a wide array of forms whose exact disposal practices and ecological consequences vary.

2.2 Types of Material Waste and Their Consequences

Plastic and glass are two of the most used materials in lab equipment. For this reason, they are also two of the most common forms of lab material waste. The functions of plastic and glass in labs are often similar, though the consequences of their waste differ.

2.2.1 Plastic Waste

The United States Code of Federal Regulations defines plastic as any solid material whose principal components are high molecular weight polymers (Cornell Law School, n.d.). Using this definition, the term plastic can refer to a wide variety of substances whose material properties, like hardness and appearance, can vary quite a bit. In the context of labs, plastic is often the material of choice for single-use products. The most notable plastic products in this context include pipette tips, storage containers, dishes, and disposable gloves. Figure 2.2.1A shows a visual examples of plastic lab equipment.

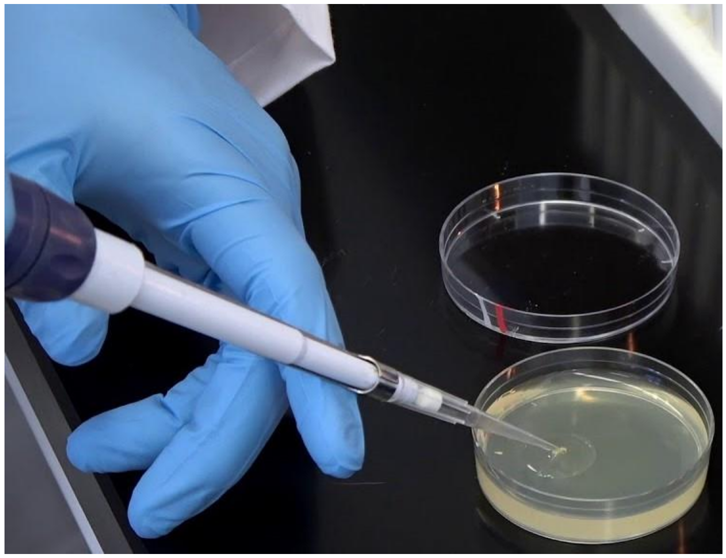

Figure 2.2.1A: Photo of someone using plastic (nitrile) gloves to handle a pipette that is dispensing liquid from a plastic tip onto a plastic dish (Addgene, 2018).

Plastics are common in labs due to their many advantages over alternative materials, like glass. An article from American Laboratory gives a good summary of these advantages (Croston, 2014). The article mentions how plastic is a very durable material that, unlike glass, is not prone to shattering. The shattering of something like glass can lead to injury and ruin experiments, so being able to avoid this risk is a big benefit. The article also brings up how plastic is typically lightweight, making it easy to handle and transport. Finally, the article points out how plastic is often very cheap, making it economical for researchers to purchase large quantities of plastic products they only use once. This fact makes plastics the material of choice for many single-use products.

Single-use lab products have many advantages over reusable ones, despite them naturally leading to more waste. For example, researchers do not need to spend time and supplies cleaning them. Additionally, researchers do not need to worry about the sterility of single-use products: they can buy them pre-sterilized and discard them once contaminated.

Due to their wide use of single-use plastic products, lab can produce significant amounts of plastic waste. According to work by scientists from the University of Exeter, research labs produce approximately 5.5 million tonnes of plastic waste annually (Urbina et al., 2015). This number accounts for approximately 2% of plastic waste generated worldwide in 2012 (Rochman et al., 2013), a year in which researchers only made up 0.1% of the global population (United Nations Educational, Scientific and Cultural Organization, 2015).

The book, *Biosafety in the Laboratory*, sheds some light on the fate of all this plastic waste (National Research Council, 1989). The book explains how researchers on-site generally first decontaminate all biohazardous plastic waste via an autoclave, which uses pressured steam to kill any microbes on the waste. This procedure notably is not sufficient cleaning to enable reuse of the plastic, as it does not wash away other contaminants (National Research Council, 1989). Once the waste is sterilized, the book details how some outside company typically picks it up and disposes of it in a landfill. The book also mentions how the company may instead bring the waste to an incinerator to be burned. In this case, the incineration will kill any microbes on the plastic so the autoclaving step can be skipped.

Although sectioning off plastic waste in landfills may be better than simply disposing of it directly in the environment, the plastic in a landfill can still cause detrimental ecological effects. One reason for this is leaching, a phenomenon explained in a paper by Teuten et al. (2019). These researchers detail how plastic manufacturers generally give their plastics chemical additives during production to aid their physical properties. Many of these additives can negatively affect the environment and are biologically active, such as bisphenol A (BPA; Canesi & Fabbri, 2015). BPA can needlessly activate specific signaling pathways in certain cells, leading to developmental, reproductive, and metabolic issues in some animal species (Canesi & Fabbri, 2015). In their paper, Teuten et al. detail how plastics in landfills can excrete BPA and other harmful additives, which then hurt wildlife by getting into the surrounding soil. Teuten et al. explain how the additives exist within pores of the plastic, and can come free given time and exposure to new chemical environments, such as those they would experience in a landfill. This process of a material excreting chemicals is called leaching.

In addition to leaching, plastic waste in landfills can also cause ecological damage by breaking off into microplastics. This phenomenon is explained in a paper by Silva et al. (2021). The paper defines microplastics as plastic particles less than 5 mm long. Silva et al. explain how, as landfill plastics are exposed to physical and chemical stress, they start to break off microplastics. These particles can then escape into the surrounding environment like leached chemicals (Silva et al., 2021). The impact of these particles is discussed in an article by XiaoZhi Lim (2021). Lim explains that the exact effects microplastics have are not fully known, though they are able to get into cells and tissues. The article details how this entry may lead to airway blockage in animals. The microplastics may leach chemicals once inside the organism, causing toxic effects (Lim, 2021).

Just like the disposal of plastic waste in landfills, disposal of this waste using incineration is not without its ecological issues. Burning the plastic at these facilities does not destroy the plastic, it just converts it into new forms which get released into the air (Wirsig, 2022). Some of these airborne chemicals can be toxic, such as dioxins, which can deposit in human tissue and lead to negative effects like cancer (World Health Organization, 2016). Additionally, around 30% of incinerated plastic waste remains as solid ash after the fact, and must be disposed of in a landfill anyways (Wirsig, 2022).

In conclusion, plastic waste can negatively impact both the environment and humans, even if properly disposed of. Considering the high quantity of plastic waste labs generate, it is important to work towards minimizing this waste, as to limit these negative effects.

2.2.2 Glass Waste

Like plastic, glass is frequently used in labs to contain and transfer substances. Common glass lab equipment includes beakers, graduated cylinders, and pipettes. A visual example of glass lab equipment is shown in Figure 2.2.2A.

Figure 2.2.2A: Photo of someone taking liquid from a glass flask using a glass pipette (University of Colorado Boulder, n.d.).

Although the functions of glass equipment often overlap with plastic alternatives, glass offers numerous advantages over plastic. An article by Deepak Bhanot (2016) highlights these advantages. Bhanot explains that glass is more inert than plastic, meaning glass containers are less prone to react with their contents. Bhanot also mentions how glass is much less likely to leach chemicals than plastic. This feature is due to glass being nonporous, meaning there are no cavities within its structure chemicals can easily hide in.

Glass lab equipment is often not single-use. This fact is due in part to glass being comparably easy to clean. Glass' nonporous nature means it is less likely for contaminants to become stuck in its structure and escape washing. Glass equipment is also generally more expensive than plastic alternatives, making it harder to justify using it only once after purchase. However, single-use glass products are still used extensively in labs, such as disposable glass pipettes.

Although most glass lab equipment is not single-use, labs can still generate significant amounts of glass waste. A study done by students at McGill University (2015) found that the college's labs collectively produce at least 250 tonnes of glass waste annually. If all 279 United States research universities (Indiana University Center for Postsecondary Research, 2021) are considered to produce this much waste, then they would generate 69,750 tonnes of annual glass waste. Considering the United States collectively produces 8.3 million tonnes of glass waste annually (United States Environmental Protection Agency [EPA], 2017), this suggests research university labs alone account for a bit under 1% of the nation's glass waste.

Just like plastic waste, glass waste can still cause ecological harm when disposed of correctly. The disposal methods of lab glass waste are nearly identical to that of plastic waste, where the glass inevitably end up in a landfill or incinerator (National Research Council, 1989). Looking first at landfills, the harm glass causes here is related to its inertness. It is incredibly difficult for nature to break down glass, leading to glass staying intact in landfills for up to a million years (Kellogg, 2019). Glass therefore stays in landfills indefinitely, just taking up space. This fact is significant, because the United States is running out of space in its current landfills. According to data from the activist group SWEEP, all United States landfills will be full by 2036, at which point we will need to build new ones (Thompson & Watson, 2018). Considering landfills can be as big as 600 acres (see Figure 2.3.2B), these constructions will destroy many natural habitats (Vasarhelyi, 2021). Overall, sending glass to a landfill can contribute significantly to the landfill becoming full, indirectly leading to habitat destruction.

Figure 2.2.2B: Size comparison of United States landfill (circled) to surrounding buildings and roads (*Landfills in Virginia,* n.d.).

Looking next at glass waste in incinerators, not much really happens to the glass here. Since glass is made of silicon oxides, a highly oxidized molecule, it cannot be burned. To burn it would mean to oxidize it further, which an incinerator cannot do. Therefore, glass in incinerators simply melts under heat and then solidifies back into a substance that must be landfilled.

Another environmental concern regarding glass is the pollution resulting from its manufacturing process. A report by the World Bank (1998) describes this process, which involves first burning and melting solid precursors in furnaces. The report goes on to describe how the melted liquid is solidified in molds to create glass. As explained by the report, this process releases numerous gases into the atmosphere, both during the combustion of its precursor and powering of its furnaces. Some of these gases are harmful to the environment, such as carbon dioxide and sulfur dioxide (World Bank, 1998). Carbon dioxide is harmful on account of being a greenhouse gas, while sulfur dioxide is such due to its ability to react with moisture to form airborne sulfuric acid (Queensland Government, 2017). This acid can lower the pH of rain, acidifying the soil and groundwater (Queensland Government, 2017). The total pollution glass production causes is at least somewhat related to the amount of glass waste being generated: if we waste less glass, we can start making less of it.

It could be argued that glass waste does not cause as much ecological damage as plastic waste. However, it still causes serious harm during its disposal and initial manufacturing. Since labs generate large quantities of glass waste, this amount should ideally be minimized as to limit these harmful effects.

2.3 Types of Chemical Waste and Their Consequences

Chemical waste in labs can be broadly categorized as either non-hazardous or hazardous. The EPA defines hazardous waste as that which can easily impose a "harmful effect on human health or the environment" (EPA, 2015b). Hazardous chemical waste in the context of labs therefore includes all unwanted chemicals easily capable of causing harm. Non-hazardous chemical waste includes the remaining unwanted chemicals.

2.3.1 Water Waste

The most ubiquitous substance in the lab that can be considered non-hazardous chemical waste is water. In labs, researchers use water as a solvent, coolant, cleaning liquid, and sometimes as a reagent in chemical reactions. A lot of the water used in these applications is not simply tap water, but rather water that has been more rigorously purified. Depending on the purification method here, the amount of water you start and end with can differ, as some is lost as waste. For example, it takes roughly three gallons of water to make one gallon of deionized water, a type of purified water (My Green Lab, 2022).

Labs generate significant amounts of water waste due to how prevalent water is in procedures, and due to the inherent wastefulness of some of its purification processes. A study done by UC Berkley found that the college's lab buildings generate almost 20% of the water waste on campus (Zhang, 2010). As noted by the study, this is over double the amount of waste generated in watering the campus, and only somewhat lower than the amount generated across all residence halls, which house thousands of people.

The water waste generated in labs, assuming it contains no hazardous chemicals, is simply poured down the drain into municipal piping. An article by the plumbing company, Express Clear Solutions (2019), gives an overview on what happens to the water next. The article details how water waste in municipal piping travels into a local sewer system, which brings it to a water treatment facility. The article goes on to describe how the workers at these treatment facilities filter out solids from the water, and use benign microbes to digest other contaminants. This decontamination process notably is not sufficient to remove any major contaminants, like hazardous chemicals (Kõrgmaa et al., 2020). The article finishes by describing how the facility workers, once they have treated their water, transport it out of the facility and into the surrounding environment.

Water waste disposal essentially recycles the water back into the Earth, though this does not mean the process is harmless to the environment. As described in a paper by Zawartka et al. (2020), the operation of water treatment facilities creates greenhouse gases like carbon dioxide, methane, and nitrous oxide. The paper explains how these gases mainly come from the treatment facilities' microbes, which excrete them in metabolism. Zawartka et al. also investigated certain treatment facilities in Poland and found they each generate around 11 kg of caron dioxide annually. For reference, if all 16,000 water treatment facilities in the United States (American Society of Civil Engineers, 2017) are assumed to produce the same amount of carbon dioxide, they would collectively generate almost 180,000 kg annually. This is equivalent to the amount of carbon dioxide produced by using almost 20,000 gallons of gas in a typical passenger vehicle (EPA 2016). Therefore, the environmental impact of water waste disposal is not negligible.

In conclusion, water waste causes environmental harm due to the greenhouse gases released by its disposal procedures. Water waste should therefore be minimized as to limit the extent to which these procedures are needed. This minimization is especially relevant for labs, as they produce considerable amount of water waste.

2.3.2 Other Non-Hazardous Chemical Waste

Looking next at the other non-hazardous chemical waste labs generate, these substances vary a lot in their properties and former uses. Stanford University compiled a long list of all relevant chemicals they would consider non-hazardous waste (Stanford Environmental Health & Safety, n.d.). This list includes various solids such as sugars, certain salts, and other biological compounds. But it is important to note that these chemicals will often end up as solutes dissolved in water when it comes time to dispose of them. Stanford's list also includes various harmful substances like acids and bases that have been dissolved in water at reasonably low concentrations. The list shows that these liquid, non-hazardous chemical wastes are to be poured down the drain, while solids are to be put in municipal trash bins.

Liquid or aqueous non-hazardous chemical waste that is sent down the drain combines with local water waste and goes through the same disposal process. Limiting this waste is therefore beneficial for the same reason limiting water waste is: it reduces the extent to which treatment facilities need to be running. Additionally, having certain non-hazardous chemicals in the water being treated may increase the greenhouse gases they release. These chemicals would be things like sugars that the facilities' microbes can consume to grow more, thereby releasing more gas. However, no studies have been done to confirm this idea.

Solid non-hazardous chemical waste that is placed in municipal trash bins will follow the typical disposal procedures for solid municipal waste. These processes generally involve the trash being sent to a landfill (Chen et al., 2020). As mentioned in Section 2.2.2, we are currently running out of space in landfills. Limiting solid non-hazardous chemical waste will help alleviate this problem.

Another aspect to consider regarding landfilling non-hazardous chemical waste is that landfills are home to numerous microbes that digest waste to produce greenhouse gases (Reynolds et al., 2022). Since a lot of non-hazardous chemical waste can serve as good food for microbes, disposing of it in landfills may bolster the microbial colonies there, leading to more gas emissions.

Overall, other non-hazardous chemical waste besides water imparts similarly negative effects on the environment during their disposal. Therefore, it is a good idea to try and minimize this kind of waste in labs.

2.3.3 Hazardous Chemical Waste

Labs produce a wide variety of hazardous chemical waste, whose properties and former uses vary considerably. Most of these substances can be found on the EPA's P- and U-lists. These lists and their definitions are located on the EPA's website (EPA, 2015a). According to the site, the P-list is a collection of chemical waste forms that are in a pure form (e.g., not dilute) and acutely hazardous. The site goes on to define the U-list as the same thing, only the chemicals are not as fast-acting in their hazardous effects. Examples of substances on the P-list include sulfuric acid (a chemical reagent) and sodium azide (an antimicrobial). Looking at substances on the U-list, these include acetone (a solvent) and benzene (a solvent and reagent). Overall, most of the substances on these lists are solids and liquids, though some are gases.

Hazardous chemical waste can be considered such for a variety of reasons. On their website, the EPA summarizes these reasons into four categories: ignitability, corrosivity, reactivity, and toxicity (EPA, 2015a). The site explains how ignitability means the substance can burn easily, corrosivity means it can easily oxidize metals, reactivity means it is unstable, and toxicity means it can harm organisms. Different substances may have different combinations of these properties.

The process of disposing hazardous chemical waste in labs is more involved than that for non-hazardous waste, and requires careful consideration of each substance's properties. The beginning of this process is described in an article by Jyllian Kemsley (2009). Kemsley details how the process first involves identifying each of the waste substances, and then storing then with other substances they are compatible with. By compatible, Kemsley means the substances will not react together when combined. Once the waste is grouped like this, Kemsley says compatible wastes are loaded in large metal drums or boxes called lab packs, which are shipped away from the lab. Figure 2.3.3A gives an example of what these lab packs can look like.

The book, *Hazardous Waste Management*, summarizes everything that happens next to these lab packs (Varshney et al., 2022). The book explains how the packs arrive at a company that first treats the waste in some way to make it less harmful. According to the book, the company then sends what remains from this treatment to a landfill.

Figure 2.3.3A: Photo of a lab pack (*Mountain States Environmental Services,* n.d.). In this case, the pack is a steel drum containing various chemical bottles surrounded by an absorbent material.

Hazardous Waste Management gives many examples of treatment procedures, such as incineration. The book explains how this method converts burnable materials into more benign forms and kills any microbial contaminants in the process. For noncombustible materials, the book details a few alternative methods. One of these is chemical treatment, where the waste is reacted with some chemical species, such as oxidizers and bases, to render it benign (Varshney et al., 2022). Another alternative method is biological degradation, where specific microbes digest the waste into less harmful forms (Varshney et al., 2022).

It is incredibly important that researchers properly dispose hazardous chemical waste, as failure to do so can result in harmful chemicals ending up in places they should not be. In these instances, the chemicals have the potential to cause a great deal of harm to the surrounding people and environment. The United States Center for Disease Control (CDC) has compiled a few examples of injuries resulting from this improper disposal (CDC, 2005). In one example, an unsanctioned lab put a highly acidic solution in a municipal waste bin. The CDC explains how, when a sanitation worker went to pick up the waste, the solution spilled and gave him chemical burns.

Although the greatest harm hazardous chemical waste can cause may come from its improper disposal, its correct disposal can still have detrimental effects. The most notable of these arises during treatment via incineration. A paper by Domingo et al. (2020) explains how this incineration process, just like with plastics, can release many toxic substances in the air. Domingo et al. mention a few examples, including dioxins and furans, both of which are carcinogenic. Digging deeper into this, other researchers performed a study in which they investigated cancer rates among people living close to Spanish hazardous waste incinerators (García-Pérez, 2013). They found that these rates were significantly higher among populations closer to the incinerators. While there could be other factors causing these high rates, the proximity to the incinerators undoubtedly contributed at least somewhat.

In conclusion, hazardous chemical waste can cause harmful ecological effects when disposed of properly, and even more so when disposed of improperly. Labs should therefore be very careful when disposing of this waste and try and limit its amount as much as possible.

2.4 The Growing Movement Against Lab Waste

As we have demonstrated thus far, labs can produce considerable amounts of waste, much of which has negative ecological consequences even if properly disposed of. Therefore, labs should ideally work towards minimizing their waste, or at least minimizing its impact. In the past decade, numerous lab workers have come to this same conclusion (Relph, 2020). These individuals are now leading a movement against lab waste, some of them even forming organizations dedicated to this purpose (Relph, 2020). For example, My Green Lab is an organization founded in 2013 that advocates for minimizing the environmental impact of labs (My Green Lab, n.d.). Thanks to My Green Lab's efforts, and those from related groups, lab waste is now becoming a mainstream issue in science.

In general, lab waste and its impacts can be mitigated by applying the three R's. The three R's is a concept frequently employed in waste management, and is an acronym standing for "reduce, reuse, recycle." "Reduce" refers to directly generating less waste. In the context of labs, reducing can involve simply using less materials and chemicals during experiments. "Reuse" refers to taking items that would be waste, and finding another purpose for them. In labs, this process may involve cleaning a contaminated material or purifying a chemical to allow for its reuse. "Recycle" refers to taking items that would be waste, breaking them down, and converting them into new products. In the case of labs, this process generally involves setting aside unwanted materials or chemicals and shipping them off to a recycling facility.

In addition to the 3 R's, there are other ways to lessen the impacts of lab waste. One of these ways it to use materials and chemicals that would create less ecologically harmful waste products. Another way is to ensure the waste is being disposed of in the most proper and ecologically friendly manner. However, for both strategies it can be difficult to determine what products or methods are ecologically superior.

2.5 Waste in the Context of Teaching Laboratories

So far, we have discussed waste in the context of labs in general, but there are many different types of labs. One of these types is teaching labs. These are located in schools, typically universities, where they serve to educate students. Teaching labs host classes in which students perform experiments to learn practical skills. These experiments are ideally analogous to those that scientists perform in other labs, as this would provide students with a more real-world learning experience. Assuming teaching labs operate this way, they must generate the same sorts of waste as other labs. In this case, the teaching labs' students perform fundamentally the same work as real-world scientists, meaning they likely produce the same waste too.

It is difficult to say whether teaching labs contribute more or less to global waste than other labs. On one hand, the United States Census in 2012 found that only 40% of citizens with a life sciences degree work in a science discipline (United States Census Bureau, 2012). This statistic means that a large chunk of people with the capacity to perform lab work do not do so. However, they all likely would have spent some time in teaching labs, as this is a standard degree requirement. Therefore, it could be assumed there are more students working in teaching labs than scientists in other labs, as many scientists would have worked in teaching labs at some point, and many of the students there do not go on to become scientists. Based on this assumption, it could be argued teaching labs generate more waste globally than other labs, since the higher number of people working in them would naturally lead to more waste. However, this argument does not consider factors like how many experiments teaching lab students do each day in comparison to scientists. Even still, this exercise does demonstrate that teaching labs likely produce considerable amounts of waste.

2.6 Solutions to Reduce Teaching Lab Waste

Solutions to reduce waste in teaching labs can be divided into three categories: procedural, physical, and behavioral. Procedural solutions involve changing the experiments and practices of the labs to make them less wasteful. Physical solutions involve acquiring new equipment or items for the labs that help reduce waste. Behavioral solutions involve changing student conduct to make them naturally less wasteful.

One thing to keep in mind about these solutions is that they may result in less waste, but at the same time cause problems in other areas. For example, a solution may impart an additional cost on the lab, or negatively impact the learning outcomes of its students. Overall, it is important to consider the issues of each solution to ensure their pros outweigh their cons.

2.6.1 Procedural Solutions

An example of a procedural solution is using distillation to recover chemicals. Distillation is a common lab technique that involves heating a solution to evaporate its liquid, then condensing and collecting that liquid in a separate container (see Figure 2.6.1A). This technique can be used to isolate a liquid from other substances it is mixed with. Distillation can reduce teaching lab waste by being implemented in systems where liquids that are unusable (due to being in a mixture) are distilled into pure forms. These systems would enable the lab students to reuse chemicals. More specifically, the students could contaminate pure liquids during their experiments, but then use distillation to recover their usable form.

Figure 2.6.1A: Photo of an example distillation (Kindersley, 2019). Here, the orange solution is being evaporated, the gases from which are traveling through the long tube on the right where they condense and collect in the other flash.

Multiple colleges have implemented distillation systems to reduce waste. For example, an article from the University of Colorado Denver (2016) details how the school has begun using distillation to reuse waste acetone in their teaching labs. The article mentions how doing so has decreased acetone purchasing by 80%, indicating a great reduction in chemical waste. Related to this, a paper by Weires et al (2011)., describes how a lab course at Boise State University recovers its acetone waste just like the University of Colorado Denver. But the paper also mentions how the course includes an experiment where students get to try this recovery themselves. By doing this, the course not only cuts back on waste, but also teaches students valuable lab and waste reduction skills.

Another procedural solution to reduce teaching lab waste is to utilize microscale experiments, an idea touched upon by the book, *Green Chemistry for Environmental Remediation* (Sanghi & Singh, 2012). The book defines microscale experiments as those using small quantities of reagents. As mentioned by the book, these experiments naturally produce less chemical waste than their traditional alternatives due to simply requiring less chemicals. The book also points out how microscale experiments can produce less material waste, as the equipment needed to handle the small amounts of chemicals can also be smaller. For example, you could use a single well plate to hold chemicals as opposed to many disposable vials or tubes, thereby making less waste (Sanghi & Singh, 2012).

Many schools have successfully reduced their teaching lab waste by making their experiments microscale. An example for this is provided by *Green Chemistry for Environmental Remediation*, which details how a Malaysian school ran microscale equivalents of their typical teaching experiments. The book notes how these new experiments generated about 70% less liquid waste than their traditional analogs. Related to this, a paper by Agnes Pesimo looks at the effect on learning outcomes when replacing traditional experiments with microscale analogs

(Pesimo, 2014). The paper details how researchers had college students take a learning assessment after performing either a traditional lab experiment, or a microscale equivalent. The paper then shows how the assessments indicated the microscale students had either equivalent or superior learning outcomes for every experiment. Therefore, microscale experiments not only cut back on waste, but may also improve student education.

One more procedural solution is to change a teaching lab's material waste streams to introduce more recycling. This solution involves shipping the waste off to recycling facilities rather than landfills, incinerators, etc. For example, the lab's glass waste can be shipped off to glass recycling facilities. At these facilities, glass items are broken down into small pieces, which then get melted and resolidified into new glass items (Jacoby, 2019). All forms of glass are fully recyclable using this method (Jacoby, 2019), though some types are still harder to recycle than others. For example, the borosilicate glass most lab glassware is made of is heat resistant, meaning it can't be melted using a normal furnace (Case Western Reserve University Environmental Health and Safety, n.d.). However, certain recycling companies, such as Strategic Materials, have furnaces capable of recycling this type of glass (Strategic Materials, n.d.). Therefore, a teaching lab could in theory start sending their glass waste to a company like this to recycle said waste. Considering most teaching labs have separate disposal bins for just glass waste, this solution could be as simple as just sending those bins over to the recycling company.

Procedural solutions like distillations, microscale experiments, and glass recycling have proven effectiveness, no reduction in learning outcomes, and seemingly little cost. However, they may be difficult to implement simply because they require making significant changes or additions to a teaching lab. Big changes like this can be difficult to convince all relevant stakeholders on, and can take a while to be approved.

2.6.2 Physical Solutions

One physical solution to reduce at least the impact of teaching lab waste is to use more ecologically friendly materials in experiments. One possible example of these is bioplastics, which are discussed in a paper by Folino et al. (2020). The paper defines bioplastics as plastics that are either derived from biological sources (e.g., plants), are biodegradable, or both. It could be argued that a plastic being made from biological sources makes it more ecologically friendly, as this means its production is more renewable. However, these productions can often have detrimental environmental effects due to factors like using toxic pesticides to grow plants (Tabone et al., 2010). On another note, it could be argued a plastic being biodegradable makes it ecologically superior, as this means it can be broken down by naturally occurring microbes (Folino et al., 2020). This fact means that the plastics may quickly degrade in landfills, thereby taking up less space. Alternatively, the plastic may be able to avoid the landfill altogether by being disposed of via composting (Folino et al., 2020). However, all this matters very little considering many biodegradable plastics contain toxic additives, just like traditional plastics (Zummermann et al., 2020). This property means that although the plastics can be easily broken down by nature, doing so can release toxins into the environment, possibly hurting wildlife.

Overall, bioplastics may be better for the environment than normal plastics, but they are certainly still detrimental.

Another aspect to consider with bioplastics is that, at least in the context of lab equipment, they are typically more expensive than traditional plastic alternatives. For example, the company Eppendorf sells bioplastic 5.0 mL tubes for $0.55 per tube, while their traditional plastic alternative is only $0.44 per tube (Eppendorf, n.d.). Between the premium cost for lab bioplastics and their negative ecological impacts, bioplastics do not seem like a great solution.

Another physical solution to reduce teaching lab waste is to dispose of it in Zero Waste Boxes by the company TerraCycle (see Figure 2.6.2A). TerraCycle's website explains that these boxes are receptacles you fill with some specific waste and ship back to the company, which processes and recycles the waste (TerraCycle, n.d.). The website's store page shows that all the boxes relevant to teaching labs cost money, but their shipping labels come prepaid. Examples of relevant boxes on the store include those for non-biohazardous plastic gloves, and those for non-biohazardous rigid plastics, like tubes. The site lists the rigid plastics box as $101 for a 11 x 11 x 20" container, which could in theory hold 40,000 1 mL microcentrifuge tubes. Based on this number, the box seems like a small cost for the amount of plastic waste it prevents.

Figure 2.6.2A: Photo of TerraCycle's Zero Waste Boxes (TerraCycle, n.d.).

Even though physical solutions like Zero Waste Boxes may greatly reduce teaching lab waste without any impacts to learning outcomes, they will likely be difficult to implement. This is simply due to them costing money. It can be difficult to convince stakeholders to spend additional money on something that has no direct benefit to them, such as these solutions, which only help the environment.

2.6.3 Behavioral Solutions

Behavioral solutions to reduce teaching lab waste involve limiting student actions that cause excess waste. Examples of these actions include students using more chemicals and materials than they need, making errors during their experiments, and improperly disposing of their waste. The last action here may not directly create excess waste, but improperly disposing of waste can worsen its ecological impact.

One behavioral solution that may reduce how often students use unneeded amounts of substances is to provide the students with additional instruction. This instruction would be given by the lab's teaching staff, and include ways for students to limit the amount of materials and chemicals they use in each of their experiments. For example, this instruction could involve teaching students when it is okay to use a pipette tip multiple times in a row instead of getting a new one. The instruction could also include giving students rough estimates on the quantity of each chemical they will need during experiments, preventing them from taking excess. From our experiences in WPI's teaching labs, teaching staff often do not give instruction like this. Perhaps because of this, we have noticed students in the labs sometimes prematurely dispose of pipette tips and often take more chemicals than they need from stock solutions. Actions like these lead to the labs' waste outputs increasing. Therefore, if providing the aforementioned instruction could prevent these actions, it may greatly reduce the lab's waste.

Another method that may minimize students using excess chemicals and materials is to use incentives. In this strategy, teaching staff would give students awards such as gift cards, special recognition, or extra credit for minimizing the waste they generate each experiment. To our knowledge, waste reduction incentive programs like this have never been applied to teaching labs, but there are many successful examples of similar programs in other contexts. One of these is the Campus Race to Zero Waste. In this program, North American colleges compete to have the lowest waste output each year, with the top performers getting awards (Campus Race to Zero Waste, n.d.). In 2022, the competing colleges collectively recycled 27.9 million pounds of waste, likely in part thanks to the motivation provided by the awards (Campus Race to Zero Waste, n.d.). Just like these colleges, teaching lab students may be motivated to reduce their waste if given incentives for doing so. This incentive program would in theory result in students being careful to not use more chemicals and materials than they need. However, the program could also backfire and cause students to jeopardize the integrity of their experiments for the sake of using less, hurting learning outcomes.

In addition to students using excess chemicals and materials, students making errors in experiments can lead to added teaching lab waste. These errors could be small, such as the students breaking glassware or spilling chemicals. On the topic of chemical spillage, researchers from the University of York found that students in their teaching labs collectively spill around 1% in volume of the chemicals they handle (Tsokou et al., 2019). Depending on a lab's scale, this amount of spillage could lead to large volumes of chemicals getting prematurely wasted. To help solve this problem, the University of York researchers monitored how much volume each student in a teaching lab spilled, then told them the negative impacts that quantity could cause. The researchers then saw that on subsequent experiments, the students spilled around 50% less chemicals. Based on this study, informing students on the consequences of their waste seems like an effective method to limit waste caused by chemical spillage. This method may even be effective when applied more generally. For example, lab instructors could teach students on the impacts of all forms of lab waste, hopefully motivating them to handle substances more carefully. This approach may additionally motivate students to not use excess chemicals and materials, making it solve multiple problems at once.

Looking next at large-scale student errors that increase a lab's waste, these generally involve students completely failing and needing to redo experiments. By making errors like this, students could end up generating double the amount of waste for their experiments. Based on our own experiences, students often make these errors when they are confused by an experiment's procedure. Therefore, these errors could likely be prevented by giving students greater instruction in what they should be doing. But, it is important that this instruction does not give too much away, as students being able to figure some things out themselves is essential for learning outcomes. One possible method of instruction that preserves these learning outcomes is to show students demonstrations (live or in a video format) of the general techniques an experiment involves. These demonstrations would be general enough to not tell students the exact experimental procedure. They would instead just give the students a clear understanding of the principles they should apply in the experiment. The demonstrations could even be distributed after students are given time to try and derive a written procedure themselves. Overall, these demonstrations should reduce how often students need to redo experiments while still preserving learning outcomes.

Another form of student error that leads to a teaching lab's ecological impact increasing is the improper disposal of waste. This action involves students putting waste in the wrong receptacle, such as pouring *hazardous chemical waste* down the drain. Errors like this can cause serious harm: the chemicals may react with something in the piping system to cause an explosion, corrosion, etc. From our time in WPI's teaching labs, we have seen many students confused by where their waste should go, making improper disposal like this probable. This issue is not unique to teaching labs. One study found that 85% of the waste bins in a clinical lab had at least some incorrect items in them (Hemani et al., 2018). However, this number dropped to 30% after the researchers hung up posters explaining where to put waste, and hosted sessions to teach proper waste disposal. Based on this success, these strategies could likely be implemented in teaching labs to make improper disposal less common. This solution would involve putting waste disposal posters, such as the one shown in Figure 2.6.3A, around teaching labs and having teaching staff put a greater emphasis on proper disposal.

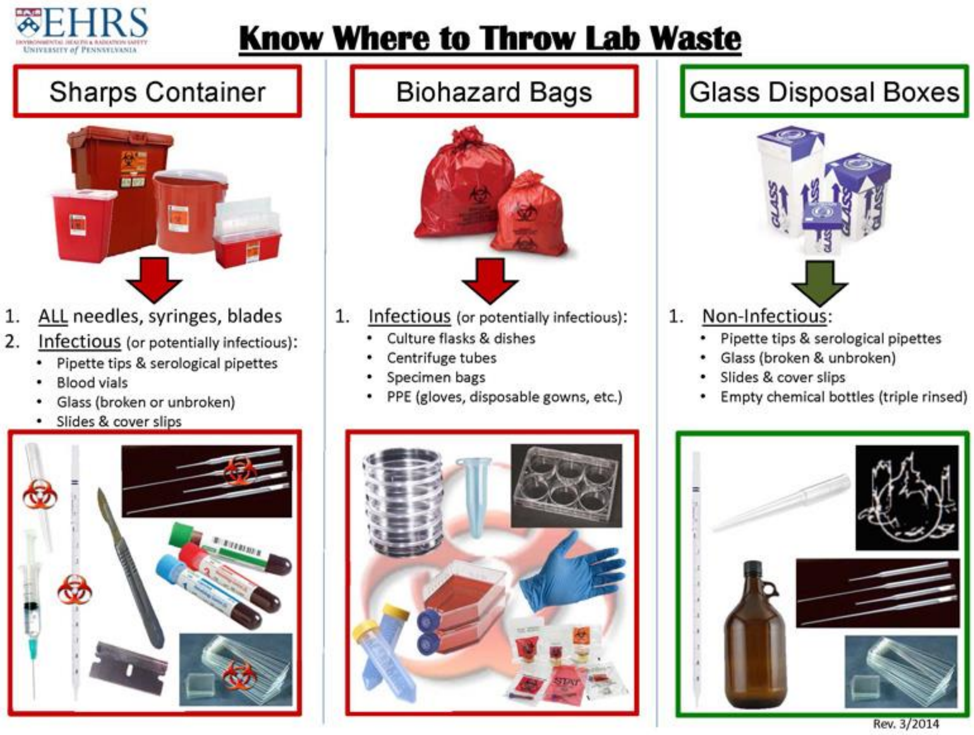

Figure 2.6.3A: Example waste disposal poster for material lab waste (University of Pennsylvania, 2022).

Behavioral solutions like the ones suggested here have many advantages over other forms of solutions. Firstly, none of them have any large costs, meaning it should be much easier to convince relevant shareholders on their implementation. Secondly, none of them would require making any major changes to how the teaching lab operate, making them quick and easy to implement. Based on these factors, the behavioral solutions seem like the best choice in trying to reduce teaching lab waste and its impacts.

3. Methodology

The purpose of this project is to quantify the amount of plastic, glass, and nitrile glove waste WPI's undergraduate biology and chemistry labs produce and propose methods to reduce this waste. Alongside this, we investigated if this waste was disposed of properly, and how WPI can encourage proper waste disposal by students. Additionally, this project identifies areas of deficit in WPI's lab material purchasing system. In order to achieve these goals, we developed the following research objectives:

1. Quantify the amount of plastic, glass, and nitrile glove waste generated in undergraduate chemistry and biology labs.
2. Investigate what changes can be made to WPI's lab material purchasing system so that waste types and amounts can be tracked and managed better.
3. Investigate the causes and solutions to excess waste generation and improper waste disposal from both a WPI administration and student perspective.

3.1 Determining the Amount of Waste Generated in Teaching Labs

In order to propose a solution, one must first understand the problem. We therefore had to determine how much waste the biology and chemistry labs were producing. By quantifying what items are the largest source of waste for WPI, we can then tailor our solutions to address them. We decided to focus our project on the chemistry and biology labs at WPI specifically. WPI has two main lab buildings, one which is called Gateway Park and another which is called Goddard Hall. Gateway Park's labs' waste output was analyzed by a separate team of this IQP in 2021. To extend our knowledge of WPI's lab waste, we chose to analyze Goddard Hall's lab waste output. A majority of Goddard Hall's labs are chemistry and biology labs. Furthermore, these labs are often student's first experience in a real lab setting. Therefore, they are more likely to make experimental errors and cause excess waste. For these reasons, we chose to focus on the chemistry and biology labs' waste output.

In a laboratory setting, experiments are conducted in a way that controls variables. Researchers want to be confident that the results they are observing are true and are not contaminated by outside sources. As a result, certain materials used in experiments are often disposed of rather than reused. For example, pipettes (which are used to transfer liquid from one container to another) are often disposed of after they are used once. This is because if the pipette was used to transfer two separate liquids, then there is a chance that the residual liquid left in the pipette might react with the new liquid and interfere with the experiment. In addition to this, two liquids reacting unintentionally could pose a safety hazard. In a similar way, materials that are biohazardous cannot be reused.

Biology researchers often work with bacteria, viruses, and organic matter. If someone were to encounter objects contaminated by these, they could become sick. Therefore, waste that could pose a health threat to other individuals is deemed "biohazardous waste," and must be disposed of in a specific manner. Biohazardous waste often cannot be recycled or reused unless it is cleaned in a way that removes the biohazardous threat. Cleaning such items is costly both in time and money, so WPI's biology teaching labs choose to use disposable plastic variations of lab materials which are designed to be thrown away after use.

3.1.1 Acquiring Purchasing Data

Our project is focusing on waste generation, so these disposable lab materials were of great interest to us. However, quantifying the amount of these materials that are being thrown out would be a challenge. The most straightforward route would be to sort through the waste ourselves and individually count the discarded items. However, this would take a lot of time and could pose health/safety risks to our group members. Instead, we chose to analyze the number of disposable materials that were purchased, assuming that they would be thrown out. So, if the labs buy 1,000 pipettes a month, it can be assumed that the labs will be throwing away 1,000 pipettes a month. This is a more roundabout way of determining plastic waste and relies on an assumption, but we believe it is the most efficient. Another advantage to this approach is that it allows our team to analyze years worth of data. If we chose to sort through the trash, then we would only have data covering a couple months.

Operating under this assumption introduces potential flaws in our data. For instance, if one material was bought in bulk and used throughout two years, then it wouldn't be accurate to look at that material's consumption on a year-by-year basis. This is because the lab would have used that material over the course of two years. However, by analyzing lab material purchasing data, it would appear it was only used over the course of one year because it was purchased for one year. This effect can be mitigated by analyzing several years because bulk orders would be averaged out over time. Due to this, we sought out the largest data set that was available to us.

The data we were looking for was all the purchases carried out by the biology and chemistry teaching labs that are still on record. This data is not publicly available at WPI, so we requested it from the chemistry and biology lab managers at Goddard Hall via email. The biology lab manager, Professor Jill Rulfs, was able to access prior biology department purchases through WPI's Procurement Office. They obtained an Excel spreadsheet from WPI's Procurement Office that contained all of the purchases carried out by the biology department at Goddard Hall between 2019 and 2022. Professor Rulfs then sorted out the purchases that were irrelevant (labor, machine purchases, maintenance, etc.) and sent the Excel spreadsheet to us. This spreadsheet contained purchases from Workday and WPI's old purchasing system, STARS. STARS and Workday record the same information, and so the data between the two systems was indistinguishable. The biology lab purchasing data we received was analyzed in several different ways too extensive to list here. A document outlining exactly how we sorted and analyzed this data can be found in Appendix B. Appendix C contains all of the raw data we extracted from the purchasing data to create the figures shown in our Findings section.

We collected the chemistry purchasing data differently than the biology data. Due to security concerns, we were unable to receive complete purchasing data from the chemistry department as we did the biology department. The security concerns were specifically related to the amount and type of chemicals WPI has on campus. The Procurement Office sent the complete Excel spreadsheet of past chemistry department purchases to the chemistry lab manager, Paula Moravek. then sorted through the spreadsheet themselves and provided us with item names and totals for disposable plastic and glass materials. In addition to this, we were given totals for gloves, which are a heavily used item in the labs. We sorted and analyzed the chemistry data the same way as the biology data. Using the purchasing data from both departments, we were able to determine the number of each disposable material purchased from 2019 to 2022.

However, the number of items is not a valid metric for comparison. An equal number of small plastic items does not contain the same amount of plastic as large items do. For example, the amount of plastic in 1000 Petri dishes is not equal to the amount of plastic in 1000 micropipette tips. The comparison of their sizes is depicted in Figure 3.1.1A. In fact, according to our collected weight data, 1000 Petri dishes is 37 pounds, while 1000 micropipette tips are 1.32 pounds of plastic. Therefore, it was important to translate item amounts to item weights. This normalized our data so that items were comparable.

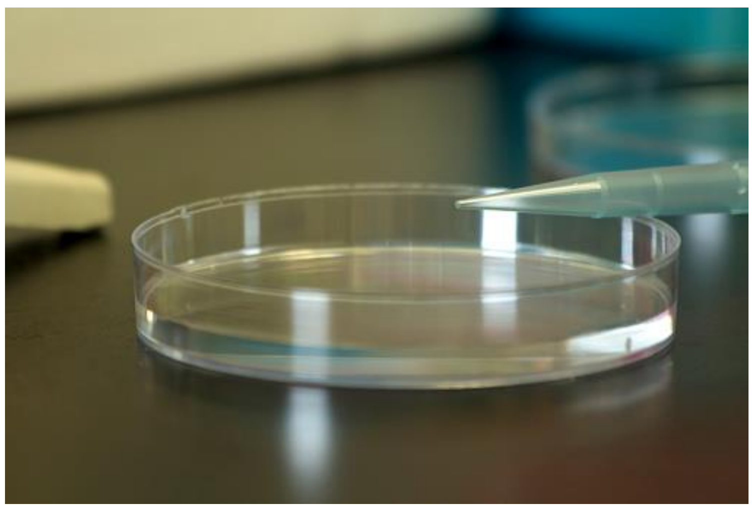

Figure 3.1.1A: A Micropipette Tip Resting on a Petri Dish

Unfortunately, WPI does not make all its purchases through the same system. The main system WPI uses is called Workday. Normally, people who want to purchase anything for the labs will login to Workday. Workday has a list of preferred vendors which can be accessed directly through the program. When an item is bought through this preferred list, several things about the item are recorded automatically by the Workday program (things such as catalog number, item amount, date, etc.). When a purchase is made outside of these preferred vendors, purchasers must use something called a P-Card, which is in essence a company credit card from WPI. When a P-Card purchase is made, information about the item is *not* recorded. Only the cost and certain expense form information is recorded. **Therefore, we were not able to analyze** P-Card **purchases at all.** Due to the lack of information in these P-Card purchases, we were not able to determine what proportion of all purchases are P-Card purchases. This poses a significant challenge to waste analysis for us and for future teams. With this new information, we decided to investigate WPI's purchasing system to see if this could be resolved.

3.2 Investigating WPI's Purchasing System

We initially did not start this project with the goal of analyzing WPI's purchasing system. However, during our data collection described in Section 3.1, we found that the system is limited and can be improved. Currently, WPI does not keep track of its plastic waste output. We believe that WPI or future researchers can use the purchasing system to determine how much material waste the labs are creating, like our team did. Therefore, we set out to investigate ways to improve the system for future use. Specifically, we sought to learn what are the limitations of the system and how it can be changed into a tool for sustainability efforts.

To get an idea of what the purchasing system looks like, we were walked through the process of purchasing an item by our advisor, Professor Manning. During this walkthrough, our team identified changes that could be made on the purchaser's end. Our goal was to have the purchaser enter the material type of what they are buying, so that future analysis of this data would not require manual sorting like our team had to do. With this goal in mind, we interviewed WPI's Procurement Office to get their thoughts on the idea and to see if it was possible. We also asked more general questions about how the system functioned and what information they had for each purchase. In addition to this, we wanted to know if the purchasing system was working well for the Procurement Office. If it was not, it would be important to address those issues in our recommendations. If the system was not working well, then it would be harder to use it to keep track of waste. The Procurement Office deals with the purchasing system the most, so we felt that they were the best people to interview about it. We generated recommendations for the purchasing system based on the challenges we faced acquiring/analyzing the purchasing data. We used the additional context we learned from the purchasing system walkthrough and Procurement Office interview to refine our recommendations further. The questions we asked the Procurement Office can be found in Appendix D.

3.3 Analyzing Waste Generation and Improper Disposal in Teaching Labs

To minimize the output of lab waste from WPI's undergraduate lab courses, it is necessary to determine the factors contributing to the output of waste from those lab courses. Investigating these factors will allow solutions to be devised according to the nature of their contribution to waste output.

3.3.1 Surveys

We attempted to identify such factors in two distinct ways. First, we surveyed students who either have taken or are currently taking an undergraduate chemistry or biology lab course. Second, we surveyed instructors and teaching assistants (TAs) for these same labs. Each survey was created using Qualtrics. We chose to create surveys because the 2019 team of this IQP found them to be insightful for their investigation of the Gateway Park labs. Therefore, we wanted to extend their research by creating surveys for the Goddard Hall labs. We chose chemistry and biology lab courses because they align with our focus and purchasing data. Before creating the surveys, we brainstormed ideas we believed would help reduce excess waste based on our own personal experience in the labs. These surveys were created early in the project, so we did not have data available for us to work from. We also came up with ideas that we believed would prevent improper disposal of lab waste by students. When some lab waste is improperly disposed of, it cannot be recycled. If there was a recycling program, the disposable glass would be collected in a special container in Goddard Hall labs. If a dram vial, which is a glass vial with a plastic cap, is put into this container with its cap, then they would no longer be recyclable. The more students who dispose of waste properly, the more these glass items could be recycled. In total, we devised four solutions the biology and chemistry labs could implement to address both problems. We tried to come up with ideas that ranged from extremely simple (like new posters), to more complex, department-wide programs. The solutions we asked students for feedback on were:

- Waste disposal posters
  - Posters which are tailored to each experiment that visually demonstrate how the reagents and products of the experiment should be disposed.
- Waste reduction instruction for every lab
  - Before an experiment begins, the lab instructor would discuss important chemicals used and/or generated in the experiment. They would tell the class where and how they should be disposed of. The instructor can also give tips for reducing waste or give estimates of how much reagents each group should be using.
- Experiment Tutorials
  - Video tutorials students can watch that will demonstrate how the experiment is done. They won't contain specifics but will give the students a general idea of what to expect before they enter the lab.
- Incentivization Programs
  - A monetary, grade, or food-related incentive for individual students or classes to use less waste. Exactly how this program would work would be left up to WPI administration or the lab instructors themselves.

More information about our initial proposed solutions can be found in section 2.6. The full student survey can be found in Appendix E, and the full professor/TA survey can be found in Appendix F.

In both surveys, we wanted to know how students, TAs, and professors felt about our ideas. If the students and lab instructors liked our ideas, then we would have a more convincing argument to implement them.

3.3.2 Survey Creation Specifics

The survey was split into five sections: Qualifications, Demographics, General Opinions, Opinions on Labs, and Solution Opinions. The Qualifications section just asked if the respondent consents for our team to use their data and if they have ever taken an in-person biology or chemistry lab course. If they responded "no," then the survey would end, and their responses would not be recorded. This was done so that students whose data could not be used were not included in the data set. The survey would then move on to the Demographics questions. These questions asked basic demographic questions (grade level, years they took the course, etc.). One of the questions in this section would ask what type of labs the student has taken at WPI (either chemistry or biology). The survey would only display biology-related questions if the student had taken a biology lab. The same thing was done for chemistry labs. If the student had taken both courses, then both biology *and* chemistry questions would be displayed. We did this to see if opinions varied based on what courses the respondent had taken. Biology and chemistry labs function differently, so it was likely that opinions would change between them.

The General Opinions section asked the students how they felt about sustainability efforts at WPI. For example, questions included how important reducing lab waste was to the respondent, and if the respondent wanted WPI to have more sustainable lab practices. The goal of these questions was to see if the student body cared about sustainability. If they did, then our proposed solutions would align with the student body's wishes and would strengthen our argument to have them implemented. If they didn't care about sustainability, then we might have had to come up with new ideas addressing that issue.

The Opinions on Labs section was created to get a sense of how students felt going into a lab and during a lab. For example, how often a student was confused on where to put their waste or how often did they make experimental errors. With these questions, we wanted to see what areas the students were struggling with the most. If most students reported that they often make experimental errors, then we could refine our solutions to focus on reducing the amount of those errors. This is in the scope of our project because experimental errors often result in the students repeating experiments to get better results. Repeating experiments uses more materials, and therefore generates more waste.

The final section, Solution Opinions, goes through each of our four proposed solutions one by one. For each solution, students were shown an example of what the implementation of the solution would look like. For instance, the waste disposal poster section included an image of a real waste disposal poster created by another college. Respondents were asked if they would like to see this solution implemented in their biology/chemistry courses and if they believed these solutions would help reduce waste. If feedback was overall positive for a solution, then we would have a stronger argument for proposing it. The professor and TA survey had a similar layout. However, there was a new section that asked them their estimates for waste generated in each lab on a per item basis. We hoped to compare these numbers to the purchasing data to see if they aligned.

A challenge that could have been encountered with the student surveys is receiving an ample number of survey responses. This was mitigated by providing entry into a raffle for a $25 gift card through survey completion and using flyers, social media, and student emails for promotion of the survey and raffle. A large enough sample size of students would strengthen the reliability of the data. Conversely, the comparatively small number of professors and TAs relevant to this investigation made ensuring the anonymity of the respondents especially important. Instructor/TA surveys did not collect personal information, but it might be possible to reverse engineer their answers to obtain their identity. However, the questions are vague, and this would be difficult. The survey does not include controversial questions that could harm the respondent if anonymity was removed. An additional obstacle to consider is the difference in protocol and format of lab courses in the past number of years due to restrictions caused by the COVID-19 pandemic. This was accounted for by asking the years in which the respondents were taking or conducting those courses in the survey.

3.3.3 Survey Distribution

The student survey was distributed via email to all majors that would have taken a biology or chemistry lab at Goddard Hall. We were able to find out what majors would have taken these courses by looking at WPI major requirements. If a major required a biology or chemistry lab course, then we would send an email with the link to the survey to that major. In order to send emails to all students who have a particular major, we had to contact the department heads for that major. Only the department head can send an email out to all students of that department's major, so we had to ask them to distribute it for us. In order to encourage more responses, we allowed respondents who completed the survey to enter into a raffle. The winner of this raffle would be given a $25 Amazon gift card. We also put up posters containing a QR code to the student survey in several different places around campus. The full procedure of student and professor/TA survey distribution can be found in Appendix G. We attempted to distribute the professor and TA survey by again emailing the department heads. We asked if they would distribute the survey to professors and TAs who work in the chemistry and biology labs at Goddard. Unfortunately, this request was denied, so we were not able to distribute this survey. We did give QR codes to some professors and TAs, but this did not result in many responses.

Due to the fact that we offered students a monetary incentive to complete the survey, we received some spam responses. These spam responses were filtered out using Qualtrics' built in filtering tools. The student survey data was filtered using the following criteria:

- Survey progress is greater than 90%
    - This was so that only surveys which were completed would be analyzed. This number is 90% and not 100% because there were some optional questions.
- The student has taken a biology or chemistry lab course
- Response type was not "survey preview, survey test, spam, survey preview spam, spam, imported spam, EX spam."
    - This in essence filters out all responses that Qualtrics detected were spam. It also filters out our own responses that were recorded while we were testing the survey.

This filtered data was then exported into an Excel spreadsheet. Using this, tables and figures were generated for each question. A full list of all our figures for this data can be found in Appendix H.

3.3.4 EHS Interview and Lab Observations

Our team also wanted to get additional feedback and information from WPI administration. WPI has an administrative body called the Office of Environmental Health and Safety (EHS). They oversee chemical and biohazardous waste disposal at WPI. We asked EHS for their opinions on our proposed solutions (the same ones in the surveys). We also asked EHS if they have any recycling programs for WPI's lab waste, and if they did not, if they were open to creating programs. We reached out with our questions via email (Appendix I) We initially reached out to an EHS representative, but they did not have adequate information available to them. Therefore, we ended up reaching out to the director of EHS and asked them our questions.

To get a better understanding of what is happening on the ground in labs, our team observed several lab classes. Having all previously been engaged in undergraduate teaching labs at WPI, we knew from general experience in the labs that each professor instructs their lab class differently. To better understand this diversity of instructional approach and potential relationship to waste generation, we chose to observe several sections across several professors. We used WPI's course information system to determine what lab classes were happening during that term. We then emailed the professors of each lab section asking for permission to observe their class. The number of classes and professors we observed are expressed in Table 3.3.3A.

Table 3.3.3A: Distribution of lab class observations

Class	Number of Classes	Number of Professors
Chemistry 1010 (CH1010)	4	2
Chemistry 1020 (CH1020)	8	4
Biology 2915 (BB2915)	1	1
Total	13	7

We chose these classes because they are considered introductory chemistry or biology courses. Most students who take these courses are fairly new to a lab environment. Therefore, they will likely be less efficient at performing experiments and create more waste. In addition to this, we thought that if we could help with the introductory courses, then those students could bring that knowledge into their more advanced courses later on. Each lab class was observed by two team members to make sure that no important events were missed.

Prior to observing the labs, our team met and discussed our observation plans. We contacted the professors who would be running the labs and asked them for their personal lab procedure. Using this lab procedure, we were able to know what experiment the students were doing at that time. We could also see what chemicals (and their quantities) each student should be using. We used this information to form a lab observation procedure for each course. Basically, if a student veered away from the established procedure in a way that would produce more waste, then we would record that observation. For example, if an experiment was supposed to use 1 liter of water, and we noticed students using more than that, then we would record this information. Using more than the recommended amount indicated by the experiment's procedure was deemed "excess waste." We also noted how each chemical used in the experiment should be disposed of and made note of students who did not follow proper disposal procedures. Our observational approach was more qualitative rather than quantitative. We did not want to know how much students were using (as that should be covered by the purchasing data), but rather what were the *causes* of excess waste.

While observing, we noticed several issues in proper waste disposal, so we kept track of that as well. Therefore, our goal evolved to include the *causes* of improper waste disposal. These two goals will help us understand what areas the students can be helped to improve WPI's sustainability overall. The exact protocol for observations changed based on what experiment was being conducted in class, but they generally contained what the observers should be looking for specifically. For every class, we made note of what waste management/disposal instructions the professor gave prior to the experiment. Each observation group also took note of the room's specific waste management setup, including posters and written instructions on the walls. Our observation procedure for CH1010, CH1020, and BB2915 can be found in Appendix J.

However, perhaps the most important thing we recorded while observing the classes was the student's behavior. Our goal was to determine if there was a pattern between sections and professors. For example, if students struggled with proper waste disposal in every section, then that would be indicative of a problem that could use addressing. Using this information, we hoped to design solutions that specifically target student's weak points. Observation groups consisted of two team members, who each individually took notes about what they saw. Notes were then compared and compiled into one major document so that patterns could be identified.

4. Findings

The following section details how we investigated the current waste management system and evaluated the state of sustainable practices in introductory biology and chemistry labs. Evidence from our surveys and interviews was used to identify limitations in the sourcing and disposal operations for laboratory materials. The surveys gave us an insight on the current culture of sustainability in WPI introductory labs and identified areas where we can implement green lab principles into our work and research. Through interviews with various departments, it was determined that the compartmentalized nature of the departments, as well as the lack of an effective network above them to facilitate communication between them, hinder the overall clarity of the systems in place. Additionally, the authority held by some departments limits the ability for departments concerned with sustainability to enforce stronger guidelines on what supplies are acquired and by what means. This observation alongside the lack of standardized categories to sort items limits the ability to efficiently gauge the nature of the supplies possessed by lab departments. Consequently, this highlights the opportunity for aspects of the structures currently in place to be improved to better assess and implement measures for increasing sustainability moving forward.

4.1 Surveys

We administered a survey to assess student opinion on plastic, glass, and chemical use and conservation practices in chemistry and biology introductory lab classes. We collected 1,069 responses from students who have taken introductory chemistry and biology lab classes at WPI. The following criteria filtered these responses if completion of the survey is greater than 90%, the initial question of have you taken an in-person introductory biology and/or chemistry lab at WPI is answered yes, and the response type is not “survey preview, survey test, spam, survey preview spam, spam, imported spam, EX spam”, leaving us with 902 responses that were analyzed. Some questions have greater than 902 responses, but this is because some students had taken chemistry labs *and* biology labs. Therefore, some respondents answered the same question twice, once for biology labs, and again for chemistry labs.

We first queried “how important of an issue do you think reducing lab waste is”, of 902 responses, 354 (39%) and 145 (16%) responded “very important” and “extremely important”, respectively. The student survey shows that students at WPI acknowledge the environmental impact of laboratories and support sustainable practices in labs. As shown in Figure 4.1B, we asked “do students want WPI to have more sustainable lab practices”, of the 902 total responses, 325 (36%) and 273 (30%) responded “probably yes” and “definitely yes”. This shows that around 66% of the students who participated in the survey want WPI to have more sustainable lab practices.

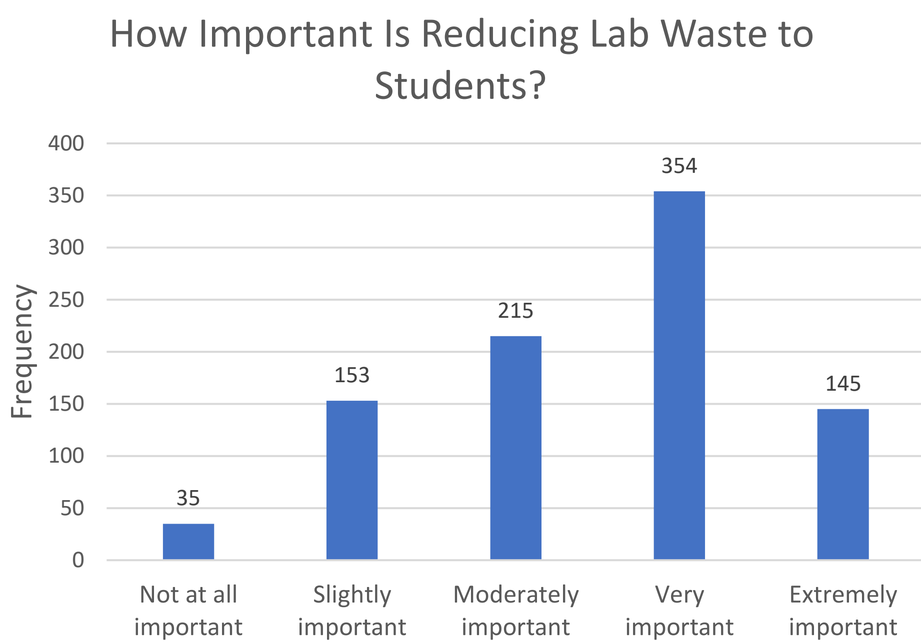

Figure 4.1A. Student survey participant responses to the question on how important an issue do they think reducing lab waste is.

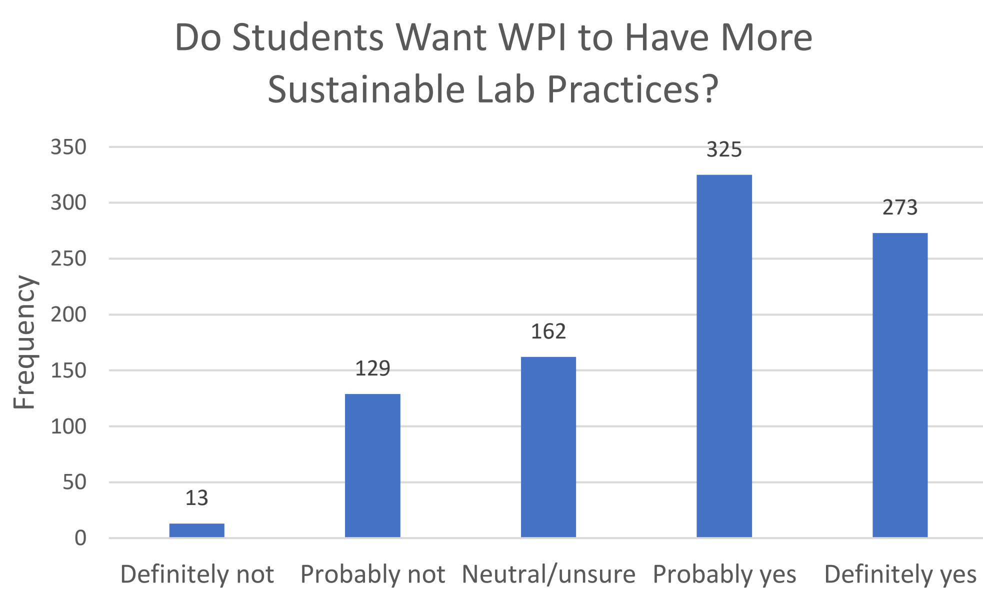

Figure 4.1B. Student survey participant responses to the question if WPI students want to have more sustainable lab practices.

In a second line of questioning, we asked students about their waste disposal behavior in lab classes. In response to the question "How often were you confused on where to put waste," of the 952 total responses (indicated in Figure 4.1C), 138 (14%) of students from chemistry labs and 103 (10%) of students from biology labs responded, "somewhat frequently". Furthermore, 47 (4.9%) students who have taken a chemistry lab and 39 (4%) of students who have taken a biology lab responded, “very frequently”. These results indicate that 42% of chemistry students and 28% of biology students somewhat frequently or very frequently are confused on how to dispose of waste. The majority of students, however, were unsure if they had improperly disposed of waste or not. This reveals that most students do not have a firm grasp on waste disposal procedures.

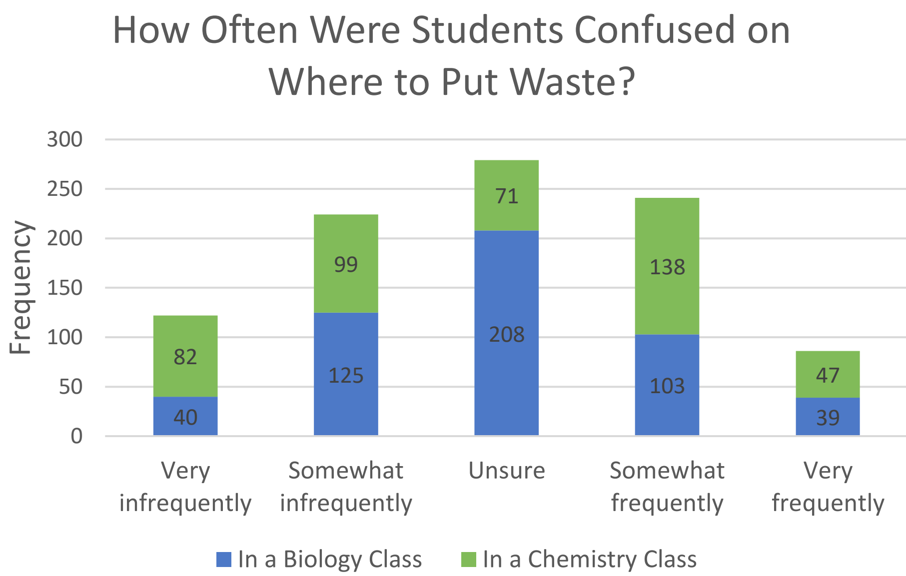

Figure 4.1C The responses of students in introductory biology and chemistry labs on how often they were confused on where to dispose of waste.

Our student surveys indicate that a majority of students are in favor of having waste disposal posters. In Figure 4.1D, over 80% of respondents said they would support the implementation of waste disposal posters in introductory biology labs, and over 50% said they would want posters in introductory chemistry labs. The 30% range in responses between the chemistry and biology labs may reflect the difference in course curriculum and the influence of waste disposal signage in a lab. Red biohazardous waste bins are commonly found in biology labs, and chemical waste containers can be seen in chemistry labs. These different forms of waste streams and distinct signage may impact the need for waste disposal posters, as 53% of respondents said the waste disposal posters would help students dispose of waste properly in introductory biology labs, and 74% said the same for introductory chemistry labs (Figure 4.1E).

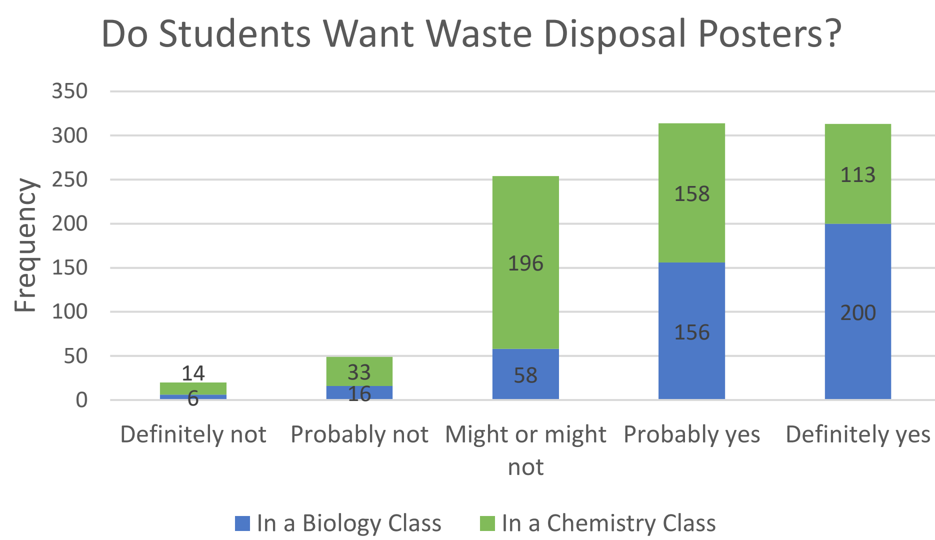

Figure 4.1D. The responses of students in introductory biology and chemistry labs when asked if they would want waste disposal posters.

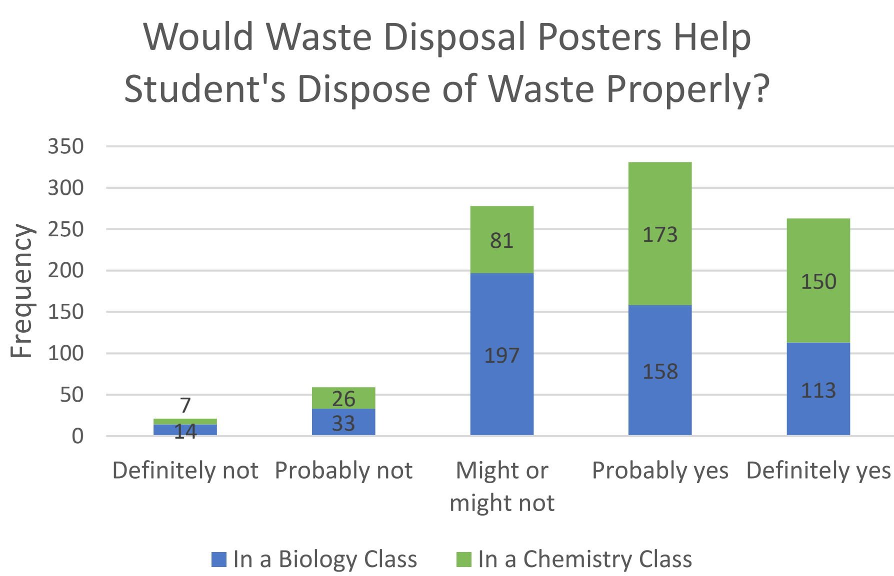

Figure 4.1E. The student survey responses of students in introductory biology and chemistry labs when asked if they believed waste disposal posters would help students properly dispose of waste.

To understand the students waste disposal practices, we asked students who have taken an introductory biology and chemistry lab class "how well do they know the lab procedure", of the 952 total responses, 254 (26.6%) of responses from both students who have taken chemistry (115 responses, 12%) and biology (139 responses, 14.6%) courses answered, "very well". For the pervious question, 156 (16.3%) responses of students who have taken a chemistry lab and 250 (26.2%) responses of students who have taken a biology lab responded, "moderately well". A significant portion of students did not fully understand the procedures when performing experiments in their introductory chemistry labs. Figure 4.1F shows how only 36% of respondents believe that they understood these procedures well before beginning the lab experiment, and 10% believe they did not understand the procedures at all. Furthermore, many participants in our survey raised issues about making errors and repeating experiments. In Figure 4.1G, only 10% of students shared they very infrequently make errors during introductory chemistry experiments, and 14% said they need to redo their experiments very infrequently.

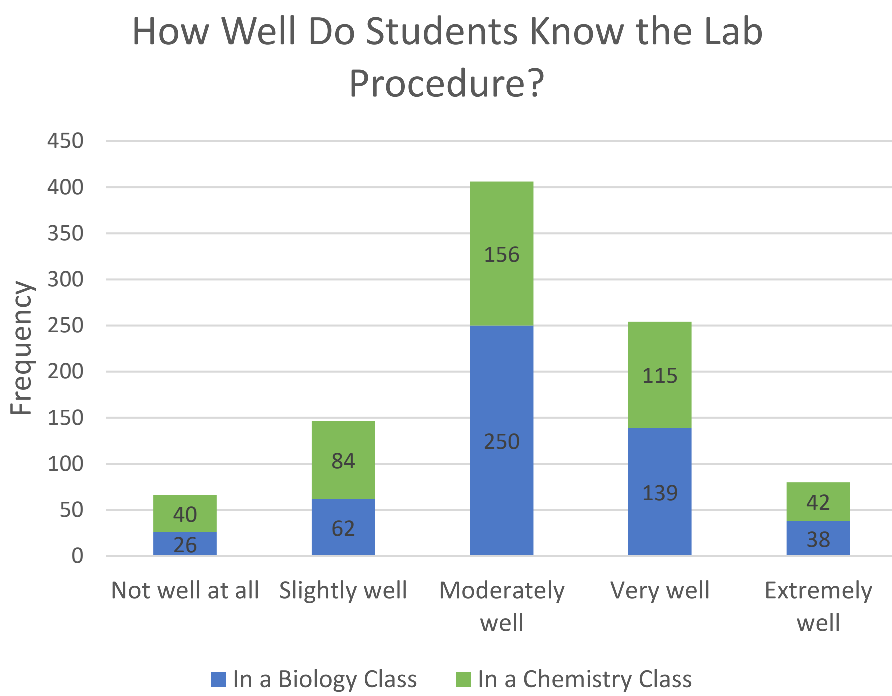

Figure 4.1F. The student survey responses of students in introductory biology and chemistry labs when asked how well they understand the lab procedures.

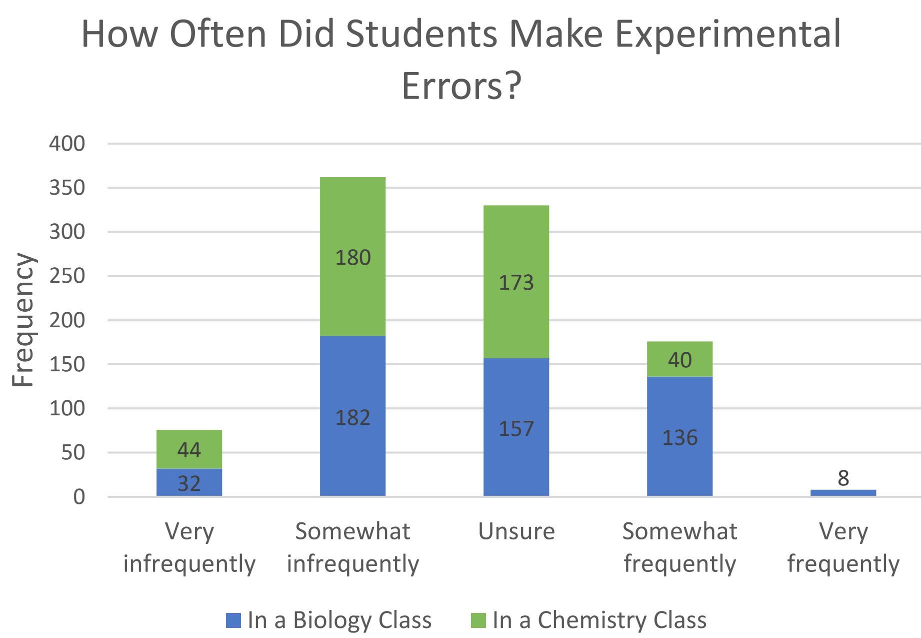

Figure 4.1G. The student survey responses of students in introductory biology and chemistry labs when asked how often they make experimental errors.

To better understand what approaches to limit waste in the lab students might be most open to employing, we next asked students if they would support the implementation of experiment tutorials for introductory chemistry labs. Figure 4.1H shows that over 70% of students responded in favor, while only 46% of students said they would want experiment tutorials in an introductory biology lab. This contrast in responses between chemistry and biology labs may be due to the difference in provided resources, such as a protocol or method of an experiment. Although around 75% of respondents believe the tutorials would reduce the frequency of repeating experiments for both introductory biology and chemistry labs (Figure 4.1I).

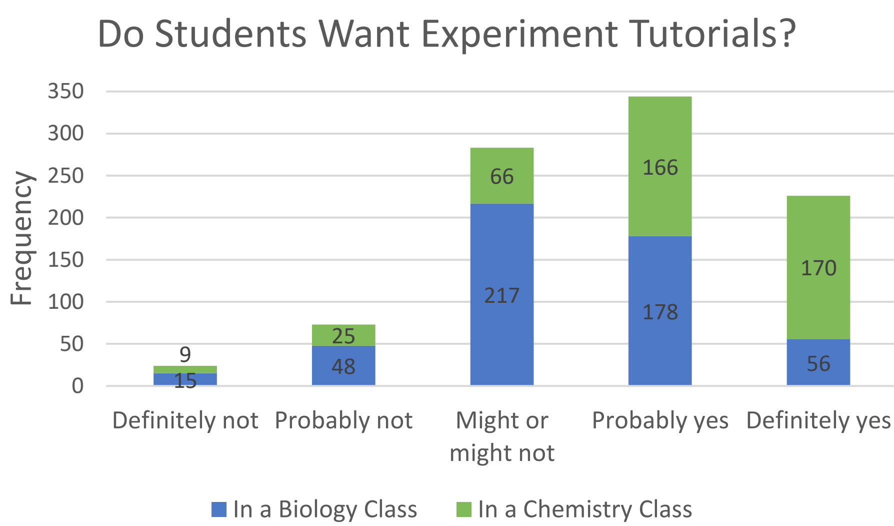

Figure 4.1H. The student survey responses of students in introductory biology and chemistry labs on if students would want experiment tutorials.

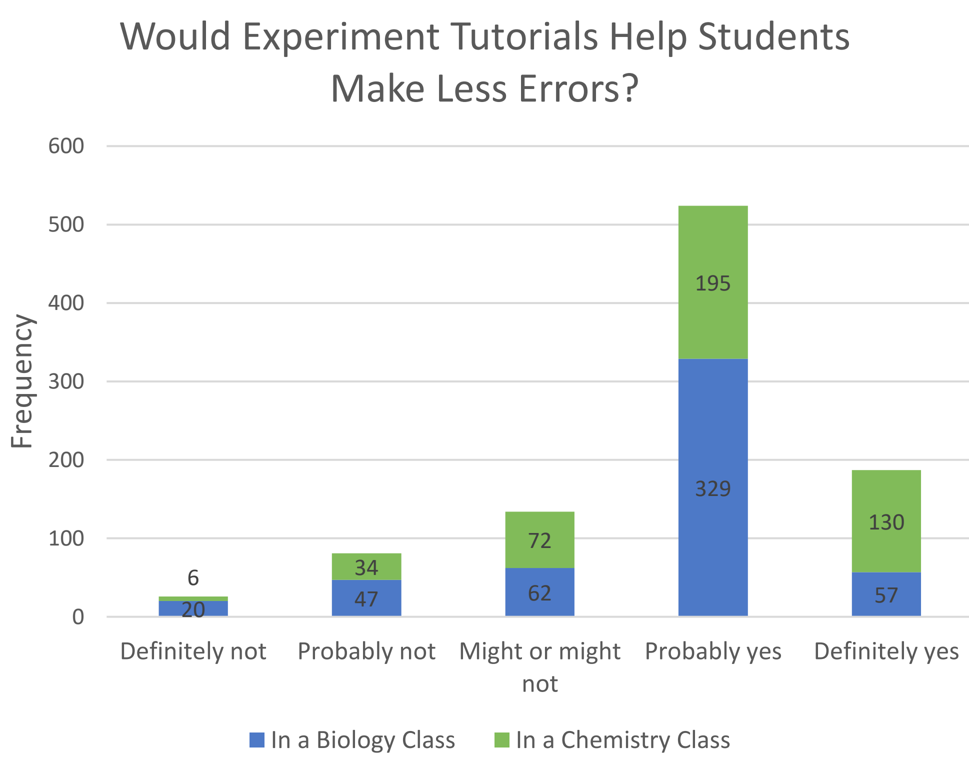

Figure 4.1I. The survey responses of students in introductory biology and chemistry labs when asked if they believed experiment tutorials would help students make less errors.

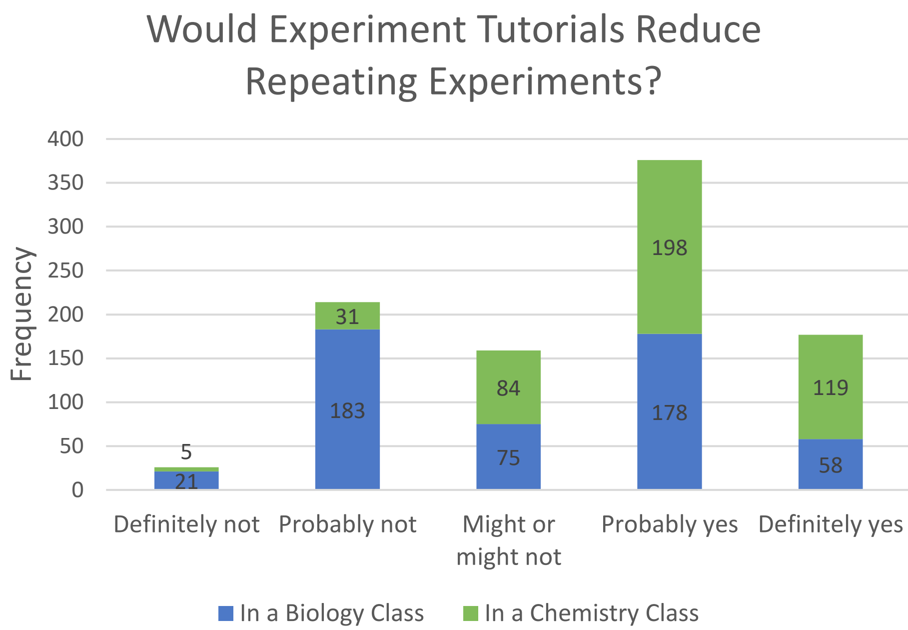

Figure 4.1J. The survey responses of students in introductory biology and chemistry labs to the question of whether they believed experiment tutorials would reduce repetition of experiments.

The proposed solution of waste reduction instruction received positive feedback, with over 75% of student survey respondents in support of this solution, and 75% indicated the instruction would have reduced the amount of waste they generated in introductory chemistry labs (Figure 4.4K, 4.4L). Of participants who have taken a biology lab, only about 50% said they favor waste reduction instruction. Although, 71% of these students said the solution would have reduced the amount of waste they produced in introductory biology labs (Figure 4.4K, 4.4L). It is clear from the student survey that WPI students are open to changes aimed at reducing the environmental impact of their introductory biology and chemistry labs.

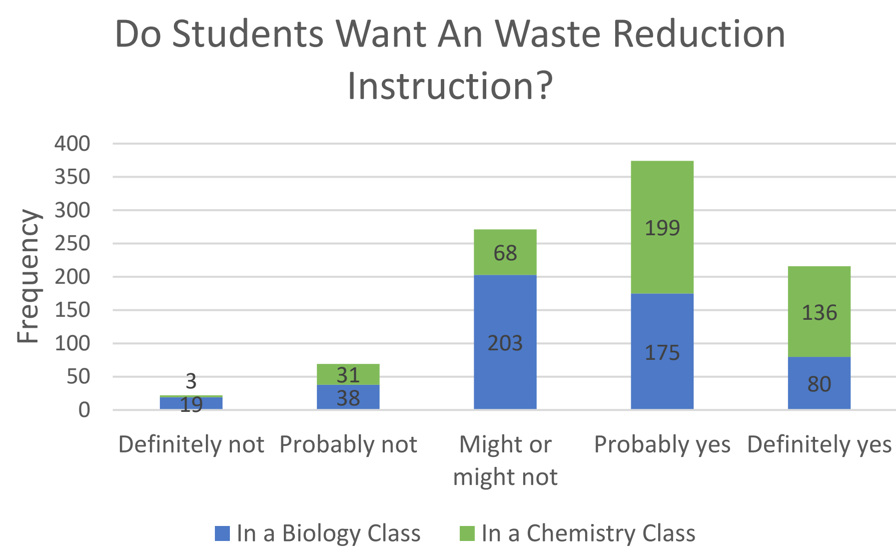

Figure 4.1K. The student survey responses of students in introductory biology and chemistry labs when asked if they would want waste reduction instruction.

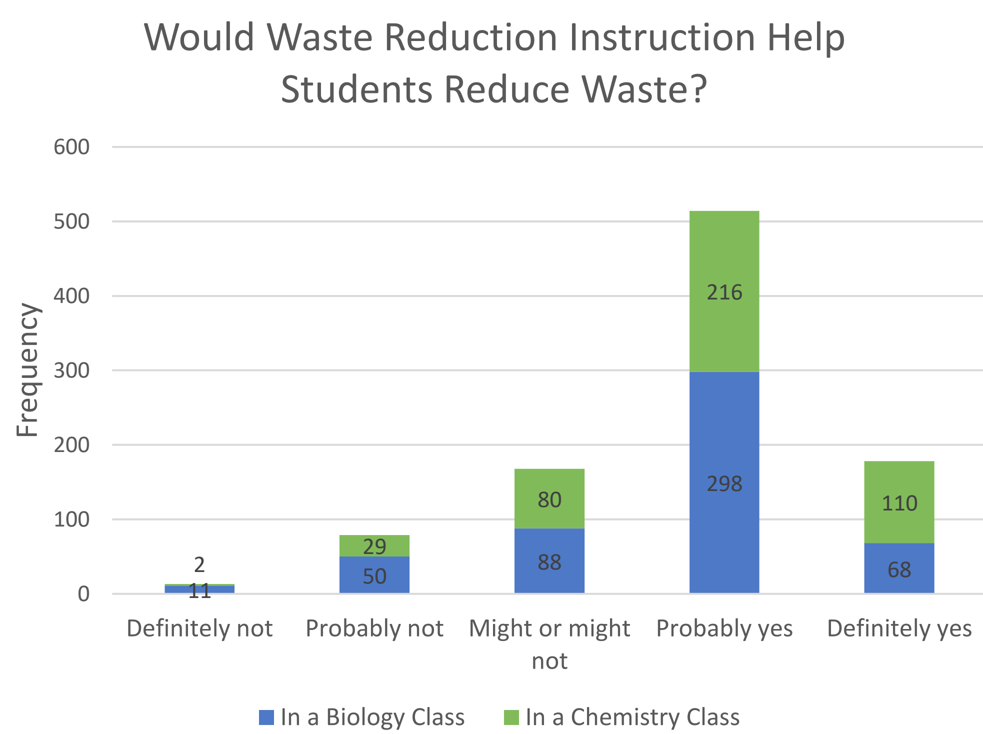

Figure 4.1L. The student survey responses of students in introductory biology and chemistry labs when asked if they believed waste reduction instruction would help students reduce lab waste.

We also asked students for their opinion on our proposed solution of implementing incentives into lab classes to encourage students to use less materials. This was the most controversial solution suggested, with only around 50% of total respondents saying they would probably or definitely support its implementation (Figure 4.4M). Many survey respondents also noted in optional text entries that this solution could lead to lab students jeopardizing the integrity of their experiments for the sake of using less and getting rewards.

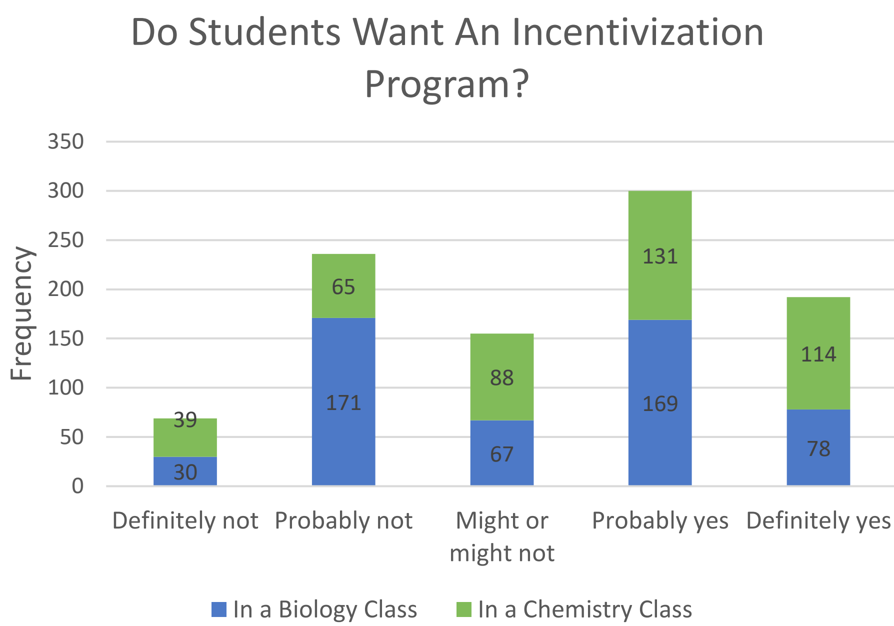

Figure 4.1M. The student survey responses of students in introductory biology and chemistry labs when asked if they would want waste incentivization programs.

We also distributed surveys to lab instructors and teaching assistants (TA) in hopes of gaining a different perspective on sustainable practices in introductory biology and chemistry labs. These surveys only received three completed responses, with one including a response from an undergraduate chemistry TA. Due to the low response rate, numerical representations of the survey data cannot be derived. In the survey, we asked how frequently materials and chemicals get recycled or reused in the introductory teaching labs, and all three responses said either somewhat infrequently or very infrequently. We also asked if any respondents were trying to implement any solutions to reduce teaching lab waste output and to give rough estimates on the amount of waste a lab class would generate in one session, by waste type (e.g., number of gloves, pipette tips). The estimates from the survey would have been used to connect the results with the purchasing data collected from biology and chemistry labs. Although due to the low response rate, an analysis of these estimates would not be representative of the perspectives of instructors and teaching assistants in biology and chemistry introductory labs.

4.2 Lab Course Observations

4.2.1 Procedures

To better understand and gain an independent assessment of how undergraduate laboratory classes handle proper waste disposal, waste reduction, and incorporating these into the curriculum, we conducted laboratory observations for the following courses: CH1010 - Chemical Properties, Bonding, and Forces; CH1020 - Chemical Reactions; and BB2915 - Searching for Solutions in Soil: Microbial and Molecular Investigations. Before observing these courses, we decided how many sections in each course to observe and went over the procedures for each lab course. The observation procedures for each lab course we observed is located in Appendix J.

In CH1010, we only observed two lab sections and two classes per section. For these lab periods, we observed the Quantum Dots lab procedure. This procedure included hazardous chemicals that must be disposed of properly. The procedure calls for cadmium oxide, oleic acid, octadecene, cadmium selenide, selenium powder, and trioctylphosphine (solid or liquid chemicals), which must be disposed of in the proper waste jug. The Pasteur pipets and any glassware used for the experiment should be disposed of in the glassware box.

In CH1020, we observed four lab sections and two classes per section. During these lab periods, we observed the Ideal Gas Challenge which involves the use of aluminum, magnesium, zinc, and hydrochloric acid (HCl). The post-reaction solutions have too low of a pH to normally be dumped down the drain (acidic). Instead, the solution must be neutralized with a base to a pH of about 5.5 for the solution to be disposed of down the sink. The procedure also calls for parafilm, weight boats, and paper clips, which can be disposed of in the normal trash.

Only one BB2915 lab course was observed. We only observed one class period for this section, since the students completed their experiments and would not need to attend the following class. For this procedure, students were working with bacterial colonies they had grown from a soil sample and performing various experiments on them. For biology laboratory courses, there are small biohazard bags, large cardboard biohazard box, biohazard sharps plastic box, a dirty dishes bin, and the normal trash bins, for students to dispose of their waste in. The small bags are for small items such as small plastic test tubes, while the larger cardboard box is for gloves and petri dishes. The dirty dishes bin is for all reusable items to be washed and dried.

4.2.2 Observations

With these procedures in mind, we developed our own procedure to reference during our observations. When observing these undergraduate laboratory courses, we aimed to assess student waste reduction, proper waste disposal, and other miscellaneous information. We first assessed whether professors incorporated proper disposal or waste reduction methods into their curriculum. This includes a presentation or a slide about the topic or having a discussion with students before and after the lab class. We also looked for how in depth these methods were. This includes if the professor discussed how each chemical should be properly disposed of or if they did not address the issue at all. Once we determined those factors, we could see how well students applied those instructions or guidance. This incorporates breaking glassware, disposing of toxic chemicals down the drain when they are supposed to be disposed of in a waste jug, or if there were waste disposal posters and how difficult it would be for a student to understand it.

For the CH1010 and CH1020 courses, the professors taught their sections differently. The professors for CH1020 did not have any information in their presentations about waste disposal, nor did they verbally explain any waste disposal procedures to their students. For example, they did not mention how much of each chemical they should use for the experiment in order to reduce waste. There was also no specific information on how to properly dispose of the waste. The professors only stated how much of each metal to use (aluminum, etc.). In CH1010, however, they did mention how to properly dispose of their waste and proper waste reduction, in at least one of the sections observed. In fact, one of the requirements for this experiment was to submit a safety analysis section of the pre-lab report. The professor had a slide in the presentation dedicated to how much reagent, or mixture for chemical analysis, each group should use. They also specified that liquid waste should be disposed of in the proper waste jug located in the front of the room and the glassware that contained the liquid waste, should be rinsed out with acetone. After it is rinsed out, the glassware should be disposed of in the proper glassware bin. Unlike CH1010, the BB2915 professors were more on par with the CH1020 professors. The professor did not specify what each student should be doing in terms of disposal or waste reduction.

Regardless of instruction or not, the chemistry lab students performed actions that led to excess waste and improper waste disposal compared to biology students. During the CH1010 lab periods, students were observed disposing of their solutions incorrectly and creating excessive amounts of waste. Students were seen cleaning out their glassware with water instead of acetone, melting the plastic cover of the thermometers, disposing of glassware in the glassware disposal bin still containing their solutions and plastic caps (dram vial caps), and almost "blowing up" their experiment. This refers to the students keeping the plastic caps on the dram vials while heating up the cadmium oxide and selenium powder mixture. If the dram vial caps are still on, the pressure inside the glass container will cause the cap to burst. In Figure 4.2.2A, there are nitrile gloves that have been disposed of in the glassware disposal bin that can be seen in the top left corner. According to one of the professors, if the glassware disposal bin contains waste other than glass, the glass cannot be recycled. Despite the information provided regarding waste disposal and reduction, we could not conclude that instruction is the cause of the student's behavior.

Figure 4.2.2A. The image above depicts the glassware disposal bin. This bin contained glassware, broken or not, dram vial caps (teal), and nitrile gloves.

During CH1020 and BB2915 laboratory periods, the professors did not provide information to their students on waste reduction or disposal. For CH1020, the professors told the students how to calculate the number of grams they needed for each metal on a PowerPoint slide but did not specify the amount of hydrochloric acid needed for the experiment. There was no mention of proper waste disposal. In BB2915, the professor did not provide any PowerPoint slides relating to waste. However, this could have been mentioned in a previous lab period that we did not observe. Despite the lack of instruction, we had observed, students in CH1020 lab sections displayed similar results to the students in CH1010 sections compared to BB2915.

In CH1020, students produced excess waste and displayed improper disposal methods. This includes breaking glassware, changing water in the beaker after each reaction for each metal concluded, dumping the resulting solution down the drain without neutralizing it first, two instances of chemical spillage, and student repeating trials. However, in the BB2915 section, students properly disposed of their bacterial samples after the experiments and showed proper disposal methods. Students were seen disposing of their bacteria in the large cardboard disposal box, disposing of glassware in the sharps box located near the benches, and cleaning their benches with disinfectant wipes. The students also did not produce excess waste such as leaving a Bunsen burner on when not in use. There were a few times where students disposed of items, such as gloves, in the wrong disposal bin, but it was not as often as the chemistry lab sections. This demonstrates that there are still ways outside of instruction that could potentially help with waste reduction.

4.2.3 Conclusions

Based on the observations above, it appears that regardless of instruction or lack thereof, students are displaying improper disposal techniques and not reducing waste. While we believe that having some form of instruction is better than none, this is no direct correlation between the two. In both the chemistry and biology laboratories, there are waste disposal posters located above the sinks. In the biology laboratories specifically, there are two disposal posters, but one is fully blocked by furniture. These laboratory posters are small, hard to read, and difficult to notice. Figures 4.2.3A depicts one example of the described posters. If the posters were larger and more descriptive, students may be able to make more conscious decisions. In addition, students are confused as to where each created waste should be disposed of. Improper disposal could be decreased if large, clear posters for each disposal bin were available.

Figure 4.2.3A. The picture above displays the disposal poster located above the sink in one of Goddard's chemistry labs. This photo specifically was taken during a CH1020 lab section. The poster is the same for CH1010 and BB2915 lab sections.

4.3 Interviews

With the aim of understanding lab management, supply procurement, and waste management from an administrative perspective, we conducted interviews with relevant personnel. This includes representatives from the Department of Chemistry and Biochemistry, Department of Biology, Procurement Office, the Office of Sustainability, the Facilities Office, and the Office of Environmental Health and Safety.

Through the interview with the Office of Environmental Health and Safety, they noted that the Office of Environmental Health and Safety is only responsible for materials and waste that are unable to be disposed of in the regular trash bin or down the drain. Aside from materials that contain or are contaminated with hazardous chemicals, they lack authority over the recycling or disposal of waste. To dispose of plastic, regulations mandate that specific protocol is adhered to if that plastic is contaminated by chemicals deemed hazardous. To dispose of the glass contained in the disposal bins in each of the labs, it is collected by custodial staff and sent into a waste recycling stream. Plastic waste that is not chemically contaminated is brought to the Rubin Campus Center to be sent into the trash compactor located there.

We emailed the Facilities Office to inquire about what happens to the waste produced from labs, particularly the waste in the general trash bins and the broken glass bins. The response we received was that both the waste in the general bins and the broken glass bins are collected by custodians and brought to the trash compactor at the Rubin Campus Center.

Upon the delivery of an ordered chemical, Environmental Health and Safety intercepts the delivery, in part due to safety reasons and regulations, but also to take note of them for inventory records. When a chemical waste container has been filled, it is collected within three days and its contents are organized to be disposed of according to regulations and protocol. The waste is then sent down the relevant chemical waste stream, which depending on the waste can include consolidation into a larger container to allow for the reuse of the initial waste container, treatment prior to disposal, or incineration.

Also of note is that Environmental Health and Safety or specifically authorized people are permitted to transfer chemicals through public spaces such as hallways and elevators, and consequently, sharing of chemical supplies between departments would only be possible within the same building. Furthermore, they stated that previously owned but still usable chemicals are received, which some labs have been reluctant to use due to concerns regarding contamination compromising their experiments. Lastly, it was explained that the safety videos provided for students taking lab courses were not produced by them, and that they only provide lab safety instruction in-person.

When meeting with the Office of Sustainability, it was explained that the sustainability department has the ability to set recommendations and create certain guidelines for purchases being made, but do not have direct authority over what a department purchases. As for ways to improve the sustainability of labs on the basis of purchases, it was explained that the guidelines and recommendations could be made more specific, and that it has been assumed that departments would take them into consideration. The suggestion was made to introduce incentives for departments to adhere to the guidelines, and that an intersection should be found between understanding of the lab setting and supply acquisition.

4.4 Purchasing Data

In order to assess the amount of waste produced in undergraduate teaching labs, we obtained purchasing for both the chemistry and biology departments. This data represents Goddard Hall's teaching labs. These results were pulled from Workday and STARS purchases. These results are focused on plastic, glassware, and nitrile materials for the academic years between 2019-2022.

For the chemistry purchasing data, the data was collected from 2021-2022. The data displays the number of disposable items purchased, what course each item was for, type of material, and the quantity of each item purchased.

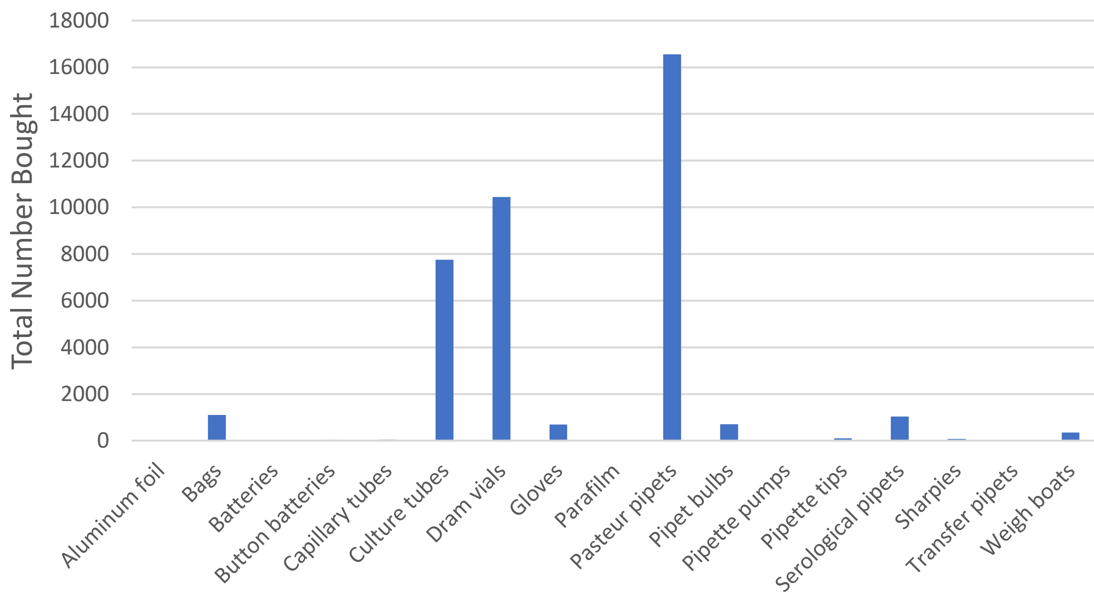

Figure 4.4A. Total number of disposable items purchased compared to the category of each item. This accounts for the chemistry teaching labs at Goddard Hall from 2021 to 2022.

In Figure 4.4A, most items purchased are glass. The largest being Pasteur pipettes with 16,560 item totals for one academic year. Dram vials are second to that with 10,440 item totals for that year. However, the number of dram vials purchased for this academic year were either plastic or glass. The purchasing data does not specify how many dram vials were plastic or glass.

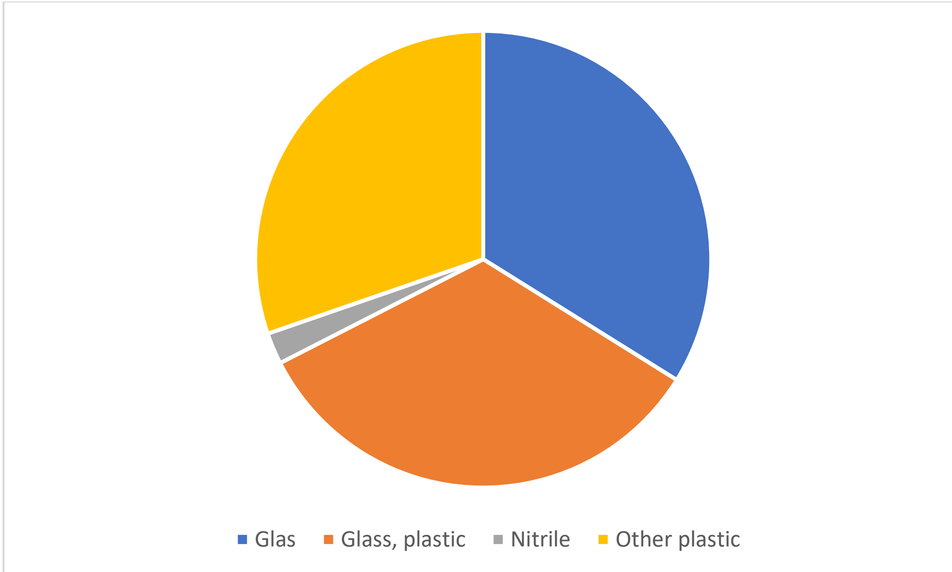

Figure 4.4B. Categories of disposable items purchased for the Goddard Hall teaching labs from 2021-2022, organized by total number. “Glass, plastic” refers to items made in part by glass and plastic.

For 2021-2022, 67.5% of the items purchased were glass products, with plastic being a close second. The percentage of plastic products (not including nitrile ones) was 63.9%. Only 2.23% of materials purchased were nitrile gloves. This may be due to covid and how much the department stockpiled, but that is unclear.

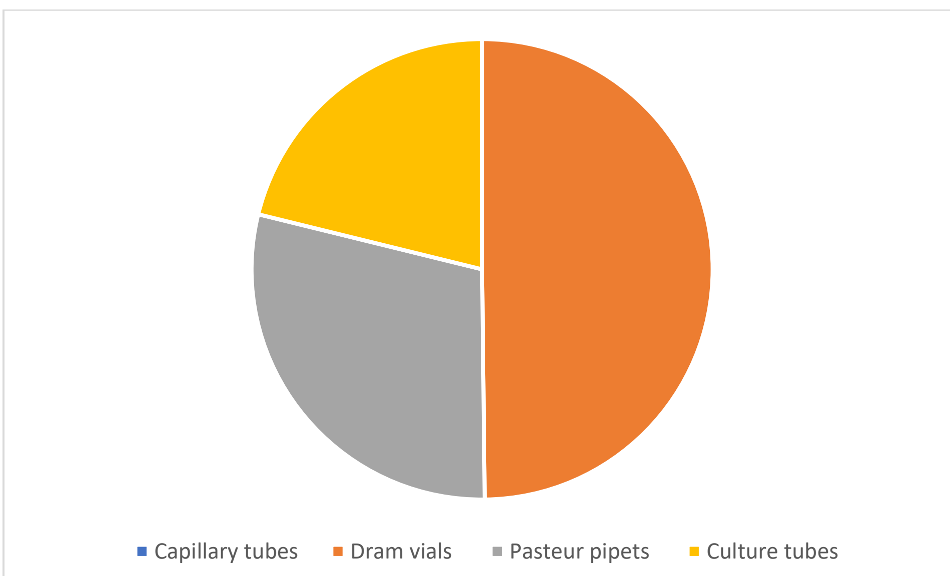

Figure 4.4C. Types of disposable glass items purchased for the Goddard Hall teaching labs from 2021-2022, organized by total number.

Out of all the glassware purchased for the academic year, Pasteur pipettes are the most purchased items which accounts for 47.6% of the items purchased. This was reflected in our observations during undergraduate laboratory courses, since the glassware waste container was filled with Pasteur pipettes. The second largest item purchased was dram vials totaling 30% of the glass items. This is also reflected in our observations. However, Figure 4.4C depicts the total weight of glass items purchased. This is because there were five types of dram vials purchased compared to only two types of Pasteur pipets purchased. The five types of dram vials purchased are as follows: 1-inch, 2-inch, 3-inch, 5-inch, and 10-inch dram vials. The two types of pipets purchased are as follows: 6” and 9” Pasteur pipets.

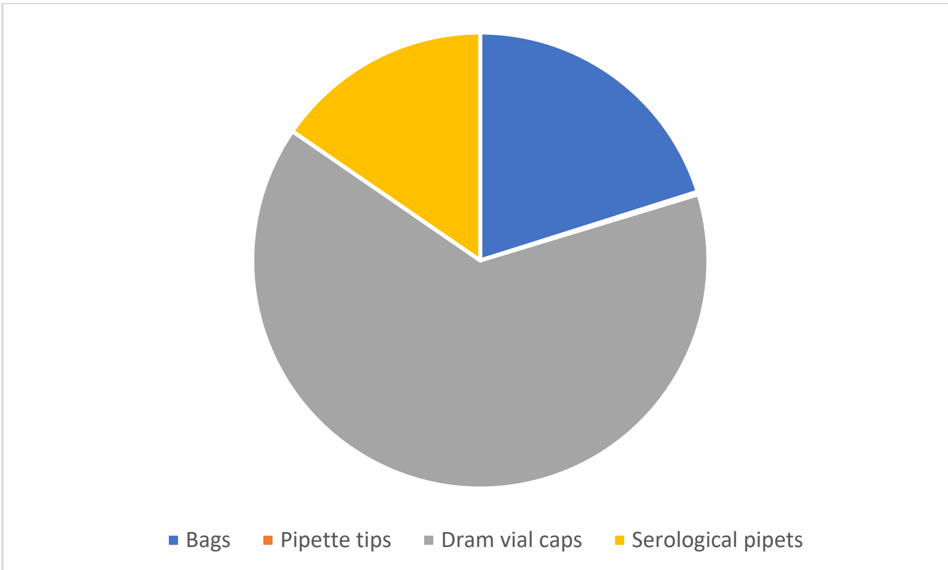

Figure 4.4D. Types of disposable plastic items purchased for the Goddard Hall chemistry teaching labs from 2021-2022, organized by total number.

According to Figure 4.4D, dram vial caps were the most purchased item for 2021-2022 totaling 82.2% of the plastic items. The second most purchased item was plastic bags, making up 8.9% of the items purchased. This is reflected in the figure above, since there were five categories of dram vials, which would make up most of the weight.

For the biology purchasing data, the data was more unorganized compared to the chemistry purchasing data but had more to work with. Since the data was not separated for us, we were responsible for sorting the information to match the chemistry purchasing data. These purchases account for academic years between 2019-2022, which is a longer time period compared to the chemistry’s data. The raw data used to make our figures for the biology purchases can be found in Appendix C.

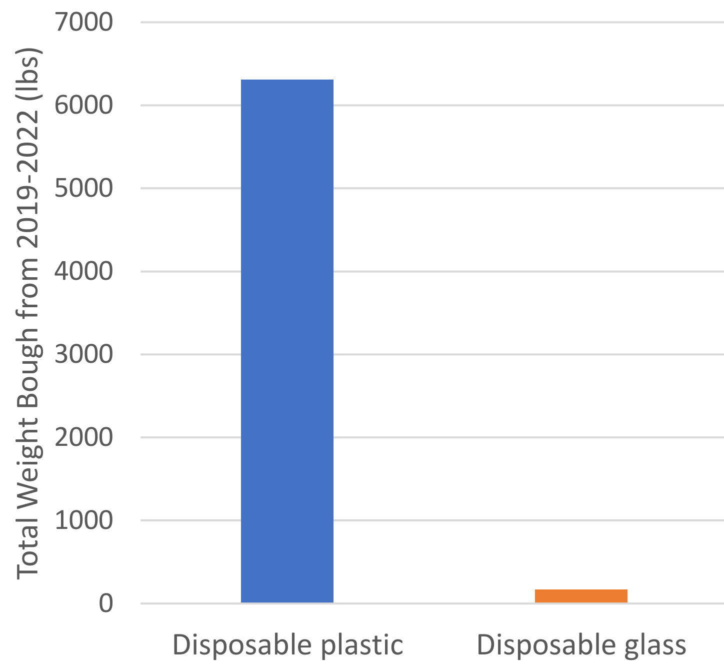

Figure 4.4E. Comparison of the total weights of disposable plastic and glass products bought from 2019-2022 for the biology teaching labs at Goddard Hall.

Disposable plastics seem to be more widely used in biology teaching labs compared to disposable glassware based on Figure 4.4E.

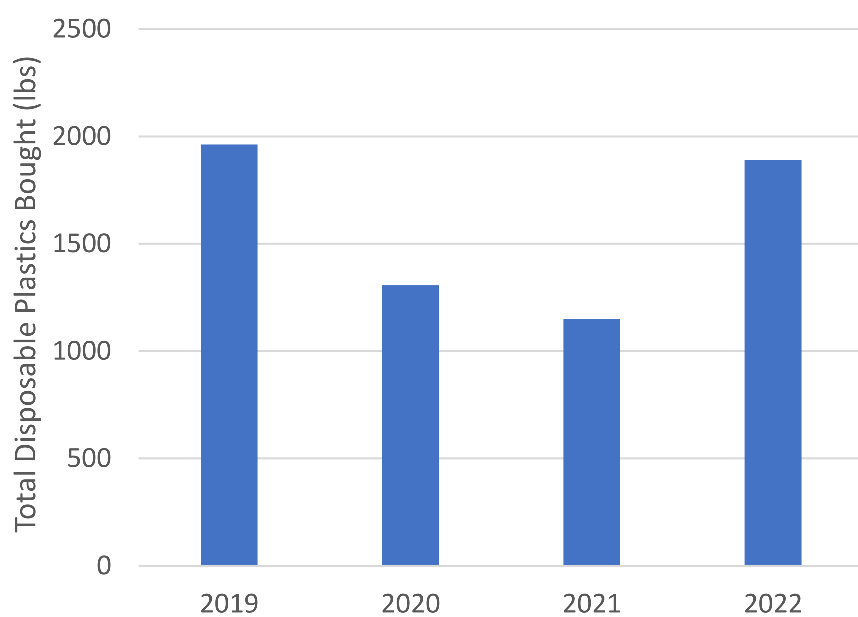

Figure 4.4F. Total weight of disposable plastic products the Goddard Hall's biology teaching labs each year.

For Figure 4.4F, it was initially assumed that the reason the total weight of disposable plastics was so small in 2021 was due to the number of students registered in-person biology teaching. However, the total enrollment was larger in 2021 than 2020 as seen in Figure 4.4O. The number of in-person biology labs dropped in 2020, likely due to COVID-19.

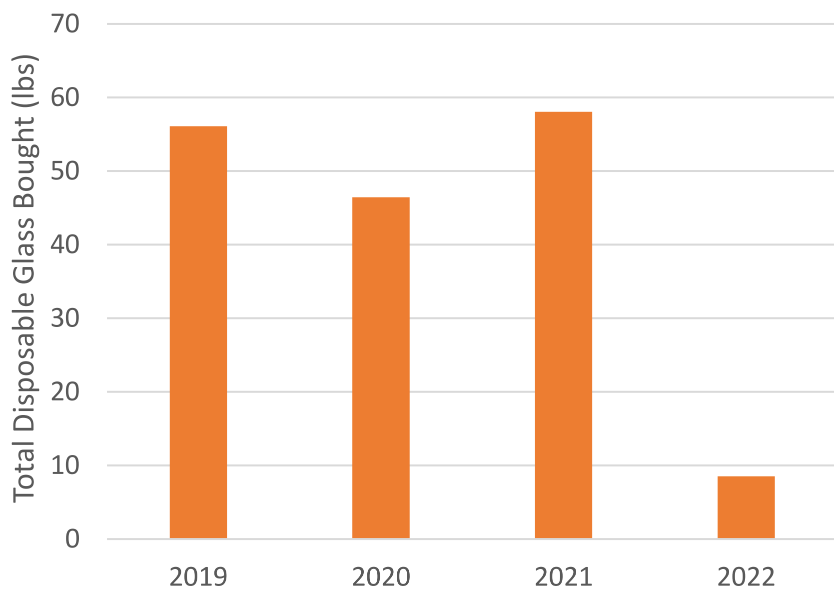

Figure 4.4G. Total weight of disposable glass products Goddard Hall's biology teaching labs each year.

Figure 4.4G above represents the number of glass disposables purchased for each year. This figure seems to correlate with Figure 4.4O, which displays the number of enrollments for biology courses between 2019 to 2022. Since the number of enrollments decreased from 2019 to 2020 due to the pandemic, the number of items purchased would decrease to account for most of the laboratory classes being remote.

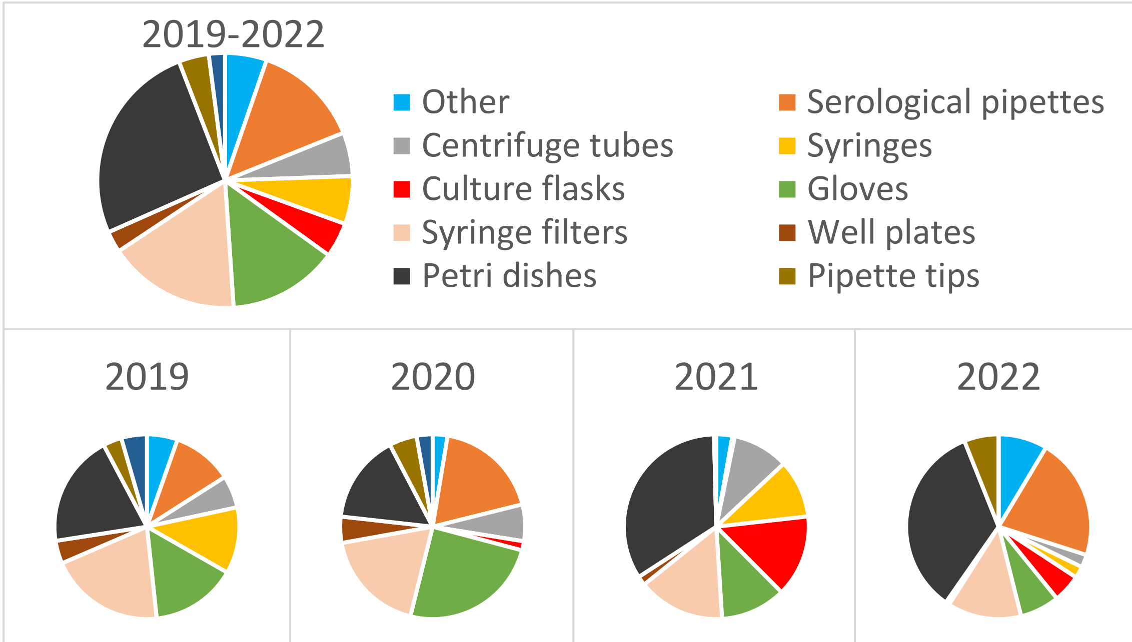

Figure 4.4H. Breakdown on the net weight each form of plastic disposable contributes to the total weights shown in Figure 4.4E and 4.4F for biology lab courses. The years indicate what total weight each pie chart corresponds to. For example, the one labeled 2019 corresponds to the total weight of disposable plastics bought in 2019.

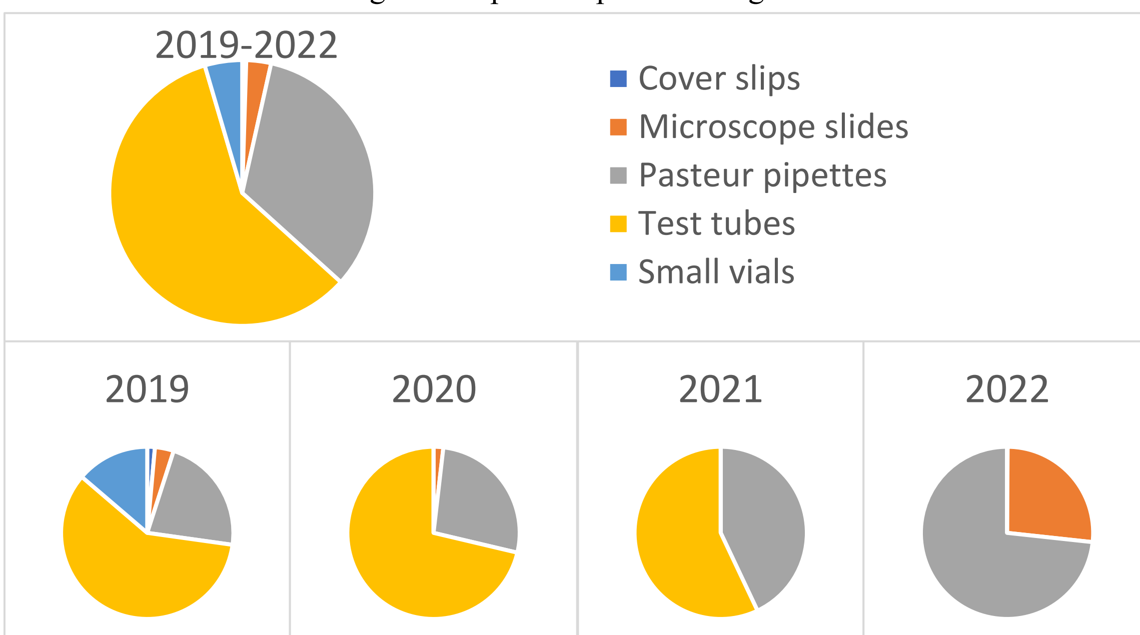

Figure 4.4I. Breakdown on the net weight each form of glass disposable contributes to the total weights shown in Figure 4.4E and 4.4G for biology lab courses. The years indicate what total weight each pie chart corresponds to. For example, the one labeled 2019 corresponds to the total weight of disposable glass bought in 2019.

The common trend for 2019-2022 is that plastic disposables are purchased more for the biology teaching laboratories compared to the chemistry department. The top items contributing to plastic waste in the biology labs are gloves, syringe filters, and Petri dishes (see Figure 4.4H). Petri dishes also contributed to the highest percentage of plastics bought by weight. The amount of Petri dishes increases each year since 2020, partially mirroring trends seen in the total enrollment of cell culture courses (see Table 4.4A).

Table 4.4A. Total enrollment in cell culture biology teaching labs each year. The ratio of these enrollments to the enrollment across all biology teaching labs each year is shown in the third column as percents.

Year	Total Enrollment in Cell Culture Courses	% Total Enrollment in Cell Culture Courses
2019	90	25.0
2020	67	19.8
2021	85	23.6
2022	91	23.7

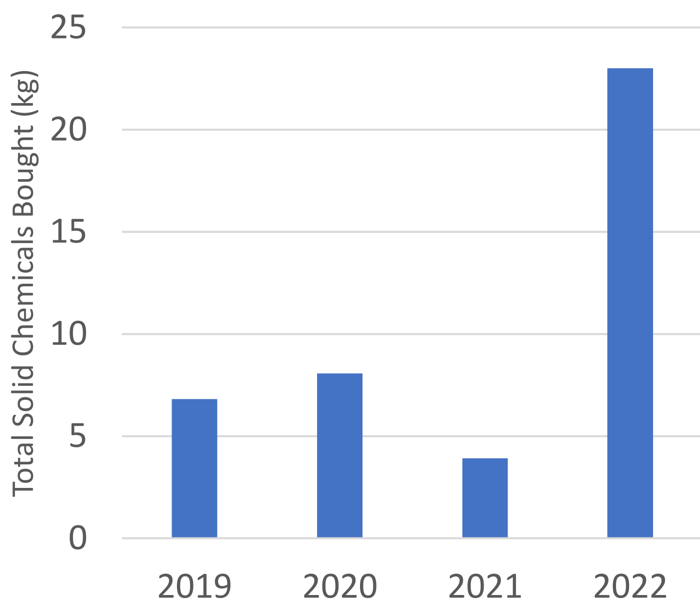

Figure 4.4J. Total mass of solid chemicals Goddard Hall's biology teaching labs bought each year.

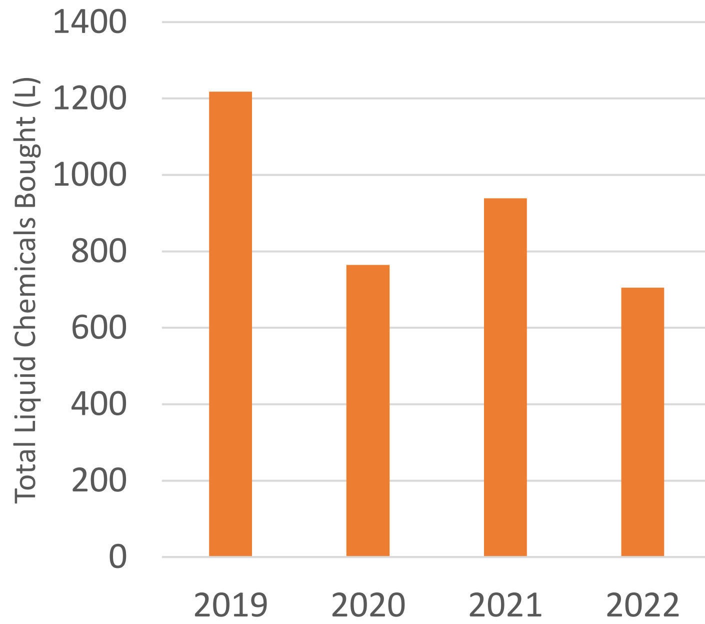

Figure 4.4K. Total volume of liquid chemicals Goddard Hall's biology teaching labs bought each year. These chemicals include both pure liquids and liquid solutions and mixtures.

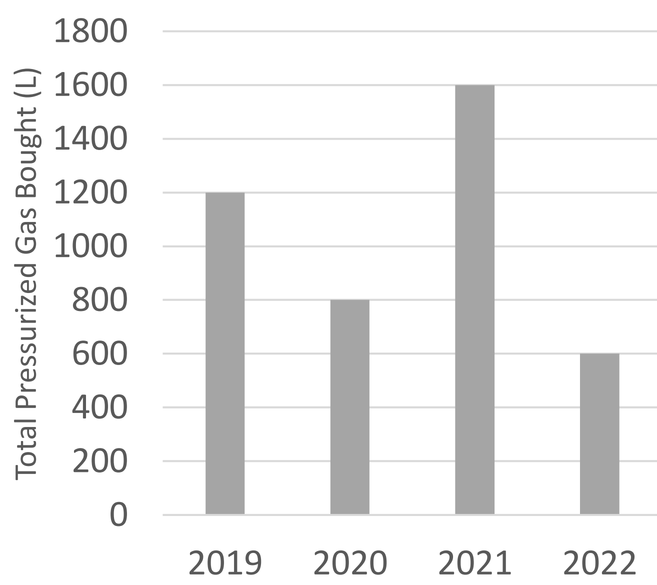

Figure 4.4L. Total volume of gaseous chemicals Goddard Hall's biology teaching labs bought each year.

For Figures 4.4J, 4.4K, and 4.4L, it is difficult to compare with the chemistry purchasing data, since this data is not readily available to us. From all the figures (Figure 4.4J, Figure 4.4K, and Figure 4.4L), the most drastic change is the increase of solid chemicals purchased from 3.9

kilograms to 23 kilograms, especially in 2022. This is found in Figure 4.4J. This is followed by gaseous chemicals in 2021 (Figure 4.4L) and liquid chemicals in 2019 (Figure 4.4K).

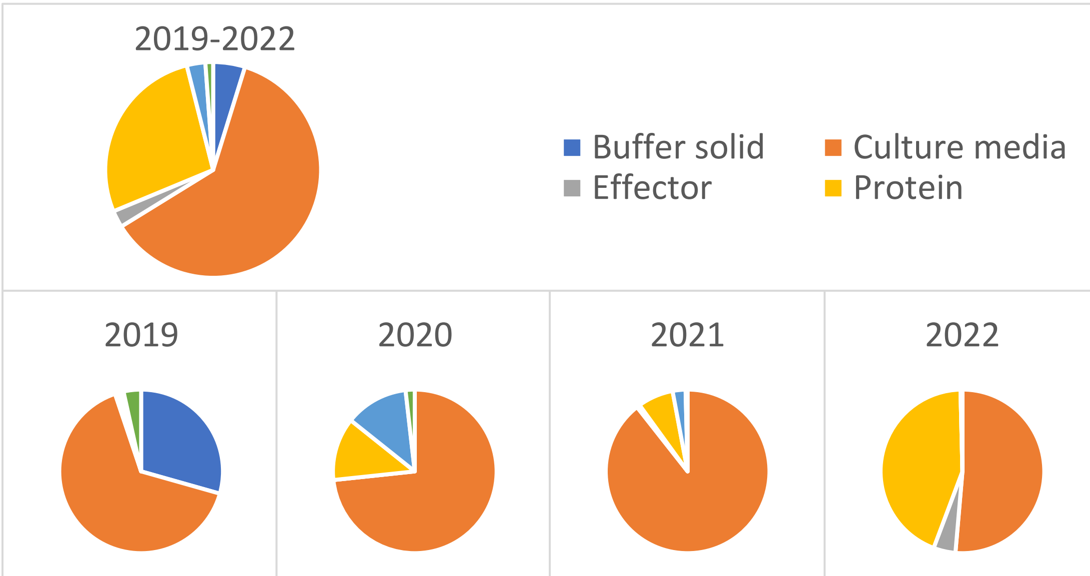

Figure 4.4M. Breakdown on the net mass each solid chemical contributes to the total masses shown in Figure 4.4J**.** The years indicate what total mass each pie chart corresponds to. For example, the one labeled 2019 corresponds to the total mass of solid chemicals bought in 2019.

Culture media is the most purchased through 2019-2022. This again corresponds with the percentage of enrollment into culture media courses. The spike in solid chemicals for 2022 is also reflected in this figure due to the number of proteins purchased for that year.

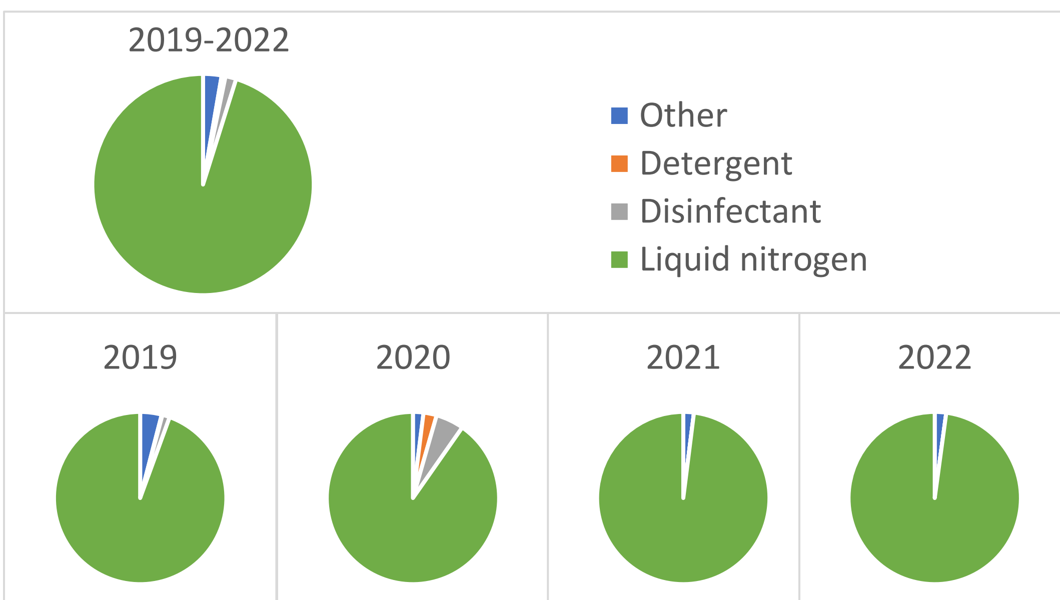

Figure 4.4N. Breakdown on the net volume each liquid chemical contributes to the total volumes shown in Figure 4.4K. The amount of liquid nitrogen purchased corresponds to the number of cell culture media purchased since liquid nitrogen is used to preserve this type of media.

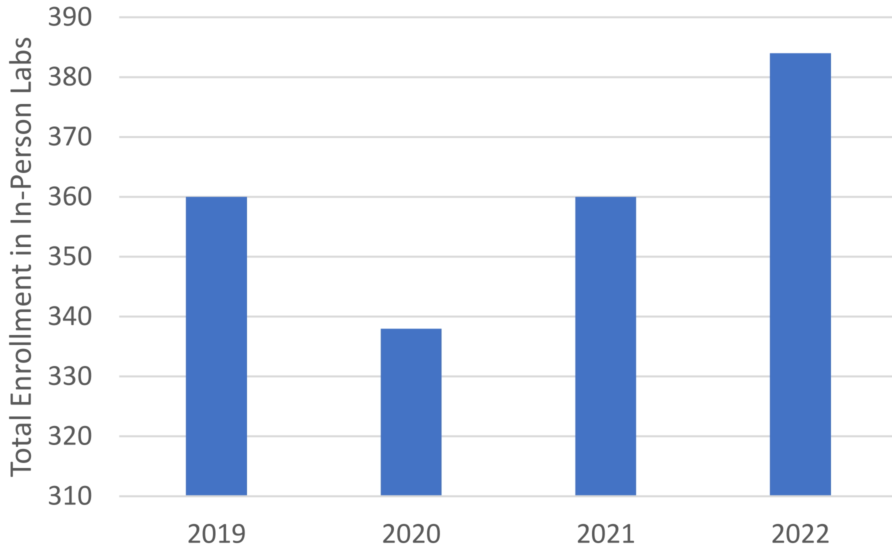

Figure 4.4O. Total number of students enrolled in in-person biology lab courses taking place in Goddard Hall each year.

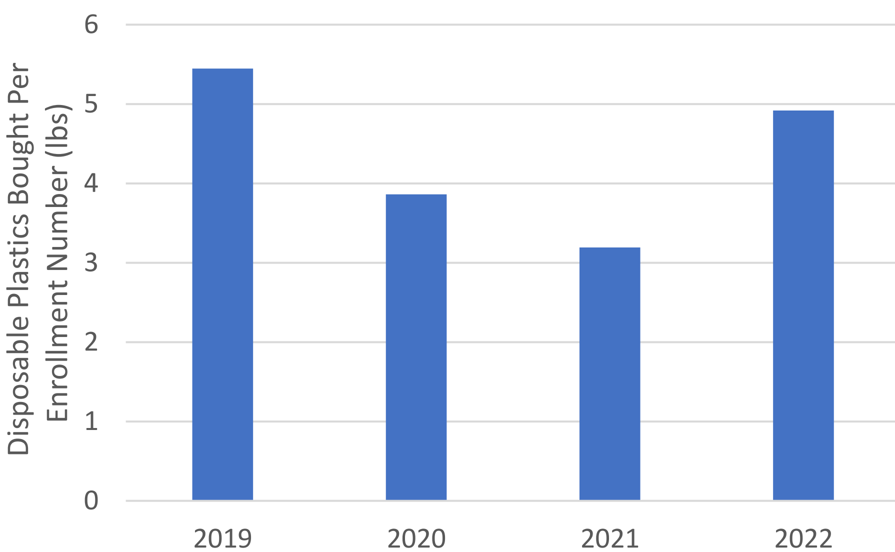

Figure 4.4P. The annual disposable plastic weights shown in Figure 4.4F are divided by each year's total student enrollment shown in Figure 4.4O.

Throughout the analyzation of the biology purchasing data, it was unclear why plastic disposables purchased decreased from 2020 to 2022. Theoretically, the number of disposables purchased should increase with the number of students enrolled in biology lab courses. In Figure 4.4P, the number of disposables purchased was the greatest in 2019. Since COVID-19 occurred in 2020 and there were no in person classes. There would be no need for extra purchases for half of the year with no waste being disposed of. If the lack of purchases in 2021 is due to the leftover stock from 2019-2020, that could explain the sudden drop in purchasing for the year 2021.

4.5 Limitations of the Data and WPI's Current Systems

It is important for any limitations in our assessment to be minimized for the solutions to be most effective. To accomplish this, we needed to gain more insight into how the procurement system works. This is the case for both the goal of mitigating the environmental impact of labs and the goal of making them more environmentally and financially sustainable. Through interviews with both the procurement offices and lab management and our preview of the procurement software, we found that aspects of the current purchasing systems' structure limit how efficiently a broader scope of understanding can be attained. This includes a lack of standardized categories to list inventory under in records, the level of detail and contributions from relevant personnel when seeking out information, and a lack of communication between departments.

One element of this limitation is the nature of the purchasing system. Among the factors contributing to the issue is a lack of standardized categories related to item composition for supply procurement to be listed in a centralized resource. Lack of information regarding the materials of lab supplies impairs sorting and assessment of purchases by categories relevant to attempts to reduce lab waste. Introducing a category to record the material an item is made of would serve to streamline the digital records maintained by procurement, enabling more comprehensive and expedient analysis of the supplies being purchased.

Furthermore, knowledge of how lab waste is managed has been limited by the amount of detail in responses provided by parties tasked with waste management. While the questions we asked some departments were sufficient in acquiring the information we needed, the information we had received in some responses was limited compared to the questions we had asked. How the lab waste is dealt with following its disposal, the structure of the recycling processes at WPI, whether implementations of additional recycling programs may be considered, and who could be asked to clarify information were all left unclear upon initial outreach regarding these questions. However, upon further outreach to the Facilities Office and the Office of Environmental Health and Safety, we learned more about lab waste disposal and the structure of WPI's recycling processes.

Additionally, some departments not contributing to the assessment of ways in which they currently operate is a limit to the aim of attaining a broader understanding. When the heads of numerous departments with requirements for a relevant lab were contacted with a request to distribute a survey, some, but not all departments assisted in distributing the survey. Lack of departmental support limited the number of survey responses received from TAs and faculty.

The lack of communication between departments regarding purchasing behavior compartmentalizes them and inhibits transparency both within administration and from outside of it. Overall, these factors highlight the extent to which the current structure of systems in place may be limiting our understanding of the full nature of their operation. Due to the limitations in the methodology and nature of information collected through the surveys and interviews, we didn't receive as much information from as many respondents as we potentially could have.

However, what information we were able to acquire is sufficient to suggest changes to WPI's systems that would aid future projects like this one.

5. Conclusions & Recommendations

We begin this section by restating our project's goal. We then assess WPI's potential for change towards the goal of our project, noting limitations and factors that would inhibit the implementation of our solutions. The solutions we arrived at are then explained, starting with lab-based solutions. This includes the introduction of nitrile glove and disposable glass recycling programs, posters highlighting proper waste disposal, generalized lab procedure tutorials, and instruction on waste reduction. Following this, we elaborate on our solutions regarding the purchasing systems in place at WPI. Lastly, we include any remaining key points and summarize our conclusions thus far.

5.1 Project Goal

From the results gathered throughout this project, it is evident that the WPI community has the interest and resources to implement changes that will reduce the environmental impact of our laboratories. The project aims to embed a culture of sustainability within WPI laboratories to reduce the environmental impact of our research and education. Our objective is to develop solutions that will decrease the consumption of single-use plastic, single-use glass, and other lab commodities generated within WPI's instructional labs without adversely affecting operations. We also hope to assess the amount of material waste generated in these labs, and the major factors contributing to this waste. The project proposed solutions to help foster sustainable practices in labs and reduce our environmental footprint.

5.2 WPI's Potential for Change

While there is an amount of waste produced in teaching labs that will be unavoidable due to the experiments being performed, minimizing that amount is still possible. The extent to which the output of waste gets diminished depends on the efficacy of the solutions in practice, but also on their capacity to be implemented. For WPI to implement the changes we are suggesting, it is necessary that relevant departments are cooperative in the effort to do so. Due to the nature of the changes being recommended, it would require that some departments contribute to the process of enacting them. For some changes, this cooperation may involve allowing certain systems already in place to be modified, or allowing posters to be placed in the lab that could inform or remind students where certain types of waste are permitted to be disposed of.

As some of these recommendations are on an administrative level, successfully implementing them depends on the degree to which the relevant departments within WPI's administration permit them. If WPI aims to improve the sustainability of the components of its operation, departments tasked with those components need to be receptive to making changes. The ability for changes to be implemented in the first place supersedes the efficacy of the methods themselves, as no change can work if it is not permitted to be enacted. This is the case regardless of a solution's efficacy.

5.3 Our Lab-Based Solutions

When initially starting this project, all of us had taken undergraduate laboratory courses in Goddard Hall at WPI, during the COVID-19 pandemic. While some of our labs were online, we did have some experience within person teaching labs. During these lab periods, we felt unprepared entering the lab period. We felt we did not have the necessary information or tools to help us understand the procedures which resulted in excess waste. We also knew that our instructors had not discussed the necessary proper waste disposal steps for each contaminant. Since we were unsure if we were performing the procedure correctly, most of us had to re-do experiments which would lead to us using excess materials that could have been avoided. Furthermore, the excess amount of materials used was disposed of incorrectly, that we assumed was from the lack of instruction. We noticed students pouring chemicals down the drain, using multiple pipettes for transferring the same liquids into different containers, and chemical spills or glassware breakage at least once during the class period. This information motivated us to want to change this behavior and prevent excess waste or improper waste disposal.

Throughout the progress of this project, we learned that our initial thesis for this project was not necessarily true. During our lab observations, we learned that whether an instructor gave information regarding waste reduction and proper disposal or not, students either performed proper waste disposals or did not. Unfortunately, there was no correlation between the two. However, we did notice that if students were unsure about the procedure, it affected their ability to reduce or properly dispose of waste. If students were stressed about their experiment and had to repeat it multiple times, it caused an excess amount of waste that could have been avoided through proper instruction. If the experiments were repeated, it left little to no time left to clean and dispose of the waste properly as it could have been. The TAs also notice this behavior from the students but are unsure how to resolve the solution, due to the nature of the curriculum. The curriculum involves the students learning the experiment as they perform it with the materials and premise of the experiment given to them beforehand. From our findings, it seems that there are plenty of individuals, both faculty and students, who are interested or want to participate in more sustainable waste disposal practices but are at different stages of this process because they are not working together.

For solutions to apply in a lab setting, suggestions we have outlined include programs for recycling non-biohazardous nitrile gloves and glass, posters indicating what can and cannot be disposed of at specific locations in the lab, tutorials for experiments, and instruction on waste reduction. The exact details of each of these solutions and their supporting reasons for implementation are laid out in the following sections.

5.3.1 Nitrile Glove Recycling Program

To address the output of used nitrile gloves, we are suggesting the introduction of some sort of program to allow teaching labs to recycle their used disposable gloves. One option we found to accomplish this is to use Zero Waste Boxes, a product by the company Terracycle.

Terracycle's website explains how these boxes are receptacles to fill with some specific waste and ship back to the company, who processes and recycles its contents (Terracycle, n.d.).

The website's store page shows that they have a line of boxes that accept non-biohazardous plastic gloves. The boxes come in three sizes: 11 x 11 x 11", 11 x 11 x 40", and 15 x 15 x 37" (Terracycle, n.d.). Each box costs money ($150, $283, and $462 respectively), but their shipping labels come prepaid (Terracycle, n.d.). We recommend putting these boxes in some or all the teaching lab rooms to divert non-biohazardous gloves from their current waste stream. A medium-sized bin from Terracycle would cost $283 but would be large enough to contain approximately 80% of the nitrile gloves that the biology department purchases annually for Goddard Hall on average.

A limitation of this suggestion is that non-biohazardous gloves would not be able to be diverted from their current waste stream with this program. This excludes a large amount of nitrile gloves from biology labs from being eligible for recycling through this program. However, very few, if any, of the gloves disposed of by the chemistry department would be inhibited by this limitation. Considering the importance and frequency of labs for courses within the chemistry department, this would account for many gloves disposed of by WPI.

The cost of the boxes for this program is relevant to the feasibility of its implementation, but the amount of gloves accounted for with the purchase of one or two boxes would make a significant difference in the impact of lab waste produced annually. The shipping labels being prepaid and included in the purchase of the boxes also addresses the concern of shipment fees.

The current method of disposal for nitrile gloves is either incineration or landfilling. Both incineration and landfilling nitrile gloves are directly harmful to the environment, as burning plastic releases harmful gases and landfilling allows it to release harmful chemicals into surrounding soil (see Section 2.2.1 for more information). As a significant amount of plastic waste output by labs consists of nitrile gloves, this results in WPI disposing of hundreds of pounds of nitrile gloves annually. If the cost of the boxes for this recycling program are at all manageable, then purchasing them would allow for a large decrease in the magnitude of harm caused by nitrile glove disposal.

5.3.2 Glass Recycling Program

The solution addressing glass waste is very similar to the solution concerning nitrile gloves and involves recycling the non-hazardous glass waste generated in chemistry and biology teaching labs. This would involve redirecting glass waste produced in teaching labs from their current waste stream to a glass recycling facility.

Glass waste is currently disposed of by incineration or in a landfill. However, since glass is made of non-combustible silicon dioxide, it melts upon incineration and resolidifies after cooling. This means the glass would need to be disposed of in a landfill regardless. This is problematic given glass's inert nature, which would mean that the glass takes up space in the landfill indefinitely. This problem is circumvented by recycling the glass instead of sending it to a landfill.

While sending non-hazardous glass to a recycling facility would require that it is separate from the rest of the lab waste, most glass is already separated from other lab waste through the glass disposal bins. Consequently, redirecting glass waste to a glass recycling facility should not require additional sorting from the rest of the lab waste.

A property of glass that would benefit this solution is that it is fully recyclable could be recycled hundreds of times without negatively impacting its quality (Jacoby, 2019). However, it would be limited by the fact that many glass lab supplies are made from borosilicate glass. Although not all recycling facilities will accept borosilicate glass, there are some glass recycling facilities that will. One example of a facility like this is Strategic Materials' South Windsor, CT facility, which is approximately 50 miles from WPI's campus (Strategic Materials, n.d.).

In terms of magnitude, the chemistry department produces significantly more glass waste than the biology department, with over 356 lbs of disposable glass products purchased by the chem department in 2021 and the biology department buying an average of 68lbs of disposable glass products annually. Across both of the departments, over 420 lbs of disposable glass was purchased in 2021 alone.

The potential cost of switching over to a glass recycling stream is also a factor, as it may be more than WPI is currently paying to dispose of glass. However, depending on the difference in cost to the current expenses, the additional cost may be worth it to mitigate the lasting impact of disposing of glass in a landfill. Even if the cost is too much to recycle all of the glass, it may be worthwhile to prioritize recycling glass from departments that use more of it than others, such as the chemistry department. Overall, any amount of glass recycling would diminish our environmental impact more than the current procedure for glass disposal.

5.3.3 Waste Disposal Posters

Another one of our recommendations involves creating waste disposal posters for the introductory biology and chemistry lab rooms. These posters would give an overview on where each lab's waste products should go. They should be hung up in their respective lab rooms, and placed in areas where they can be easily seen by students. They should also be large, such to further ensure visibility.

We specifically recommend each introductory lab room has at least one poster inside that says where all the general types of waste produced in that room should go. We also recommend that for the introductory chemistry labs, more specific posters be made for each experiment. These specific posters would be hung on the walls in addition to the general posters. Rather than just giving a general overview of where waste should go, these posters would show where each specific waste product made in the day's experiment should be placed. These posters could be laminated and given Velcro strips that attach to Velcro on the wall of the lab room. Using this approach, the posters could easily be swapped out each experiment. Figure 5.3.3A shows an example of what one of these posters could look like. But ultimately, we recommend these posters be created by the instructors of each lab to ensure total accuracy.

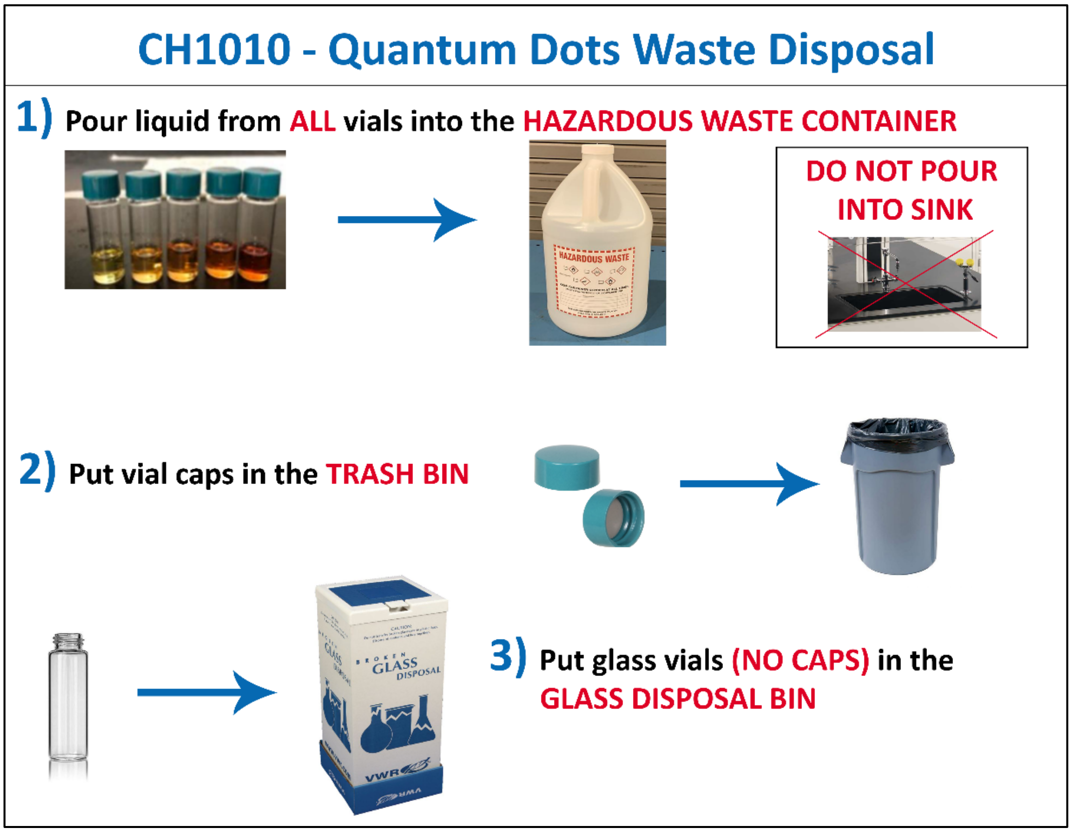

Figure 5.3.3A. Example of a specific waste disposal poster that applies to one of the experiments in CH1010.

The purpose of these posters is to reduce the frequency of improper waste disposal in the introductory biology and chemistry labs. Each type of lab waste has a specific waste stream it must go down. Improper waste disposal causes a waste item to enter the wrong stream, which can potentially lead to harm. For example, if the item is hazardous and is put into a non-hazardous waste stream, it could cause injury to staff who are handling the waste. Additionally, if a waste receptacle is going to some recycling facility, having improper items in the bin can prevent the facility from being able to recycle any of its contents. Therefore, it is very important that improper waste disposal is minimized.

Waste disposal posters have proven effectiveness at reducing improper waste disposal. As we mentioned in Background section 2.6.3, one research team found that improper disposal in a clinical lab dropped over 50% after hanging waste disposal posters (Hemani et al., 2018). However, the team also hosted waste disposal training sessions in addition to doing this, so the exact impact of the posters is unclear. Nevertheless, the posters no doubt contributed at least somewhat to the massive drop in improper disposal.

Another aspect to consider with this solution is if improper waste disposal is even a problem significant enough in the introductory biology and chemistry labs to warrant waste disposal posters. Based on our findings, the answer to this question is yes. In our student surveys, over 40% of respondents said they, to some degree of frequency, found themselves confused on where to put waste in introductory chemistry labs. This number was around 30% for the biology labs. Both these percents are rather significant fractions that the implementation of waste disposal posters would hopefully diminish.

More evidence that improper waste disposal is a significant issue in the introductory biology and chemistry labs comes from our lab observations. During our observations of CH1020, we noted numerous examples of students getting confused on where to put waste, and having to ask the instructor or TA. We also noted a few examples of students pouring hazardous chemicals down the drain. Meanwhile, in our CH1010 observations there were numerous examples of students putting improper items in glass disposal bins (e.g., plastics caps, gloves). This result is despite the fact that the instructors in these classes actually explicitly went over waste disposal at the beginning of the class. The fact that this instruction did not seem to do much to mitigate improper disposal indicates that the chemistry labs require extensive interventions to prevent improper disposal. This is why we recommend making the specific waste disposal posters in addition to the general ones for these classes.

One more aspect to consider with this recommendation is that, if the labs already have sufficient waste disposal posters, it would not make sense to recommend any additional posters be made. However, based on our lab observations this is not the case. In our observations, we noted that pretty much the only signs talking about waste disposal in the rooms were small postings by each sink saying in small text not to pour down any corrosives. The small text made these difficult to read, and on top of this, we saw they were often blocked by other objects in the lab. Therefore, the introductory biology and chemistry labs in their current state are lacking sufficient waste disposal posters.

Another reason we are recommending waste disposal posters is that the solution was highly favored in our student surveys. Over 80% of respondents said they would support implementation of them in introductory biology labs, while over 50% said the same for introductory chemistry labs. 74% of respondents said these posters would at least probably help them properly dispose of waste in introductory chemistry labs, while 53% said the same for introductory biology labs. Therefore, it seems most students would agree that the waste disposal posters are an effective intervention.

We can think of very few further counterarguments to the implementation of these waste disposal posters. One possible one is that their creation would require time and resources on the part of the lab teaching staff. However, we would argue that it is at least relatively easy to create these posters, and they can be produced in very short time spans. For example, our mock poster (see Figure 5.3.3A) took us less than an hour to create.

5.3.4 Experimental Tutorials

In order to prevent unneeded experimental errors, we recommend implementing experimental tutorials into introductory chemistry and maybe biology lab courses if needed. This would involve creating videos that demonstrate how to perform the general techniques employed in the experiment. The tutorials' sole purpose is to be administered by the lab professors to ensure accuracy. They should not reveal any experimental results or explain exactly how to perform the experiment. Instead, it should provide the general techniques students should be using in the experiment. For example, if a student wanted to isolate leaf pigments, one video could depict how to set up a silica gel chromatography column, which is needed to separate leaf pigments. For each experiment, there should be a set of videos that should be released after students turn in their pre-lab report. This way, students can still research the proper techniques and calculations on their own.

The hope of implementing this is to reduce the number of retrials that result from experimental errors. If a student makes an error during their experiment, it leads to them repeating parts of the experiment which generates more waste. During our observations, we have seen lab professors explain how to perform the experiment at the beginning of the section. However, not all students process information the same way. If there was a visual way to learn the proper techniques in addition to the lecture at the beginning, students may exhibit less retrials, or replace these explanations altogether saving class time.

Based on our student surveys, only 36% of students claimed they understood these procedures very or extremely well, while only 10% said they did not understand them at all. In theory, all students should fully understand the procedure they are following in the lab. If the students do not understand their procedure, it will lead to excess waste. In addition, only 20% of student survey respondents said they very infrequently male errors during introductory chemistry experiments. During our lab experiments, we saw five instances of students redoing their trials in CH1020 and only one instance in CH1010. This was a result of either not knowing how to set up certain components of their experiment or using the wrong reagent.

Lastly, in our survey over 70% of students stated that they would support the implementation of these experimental tutorials. Specifically, 73% said that videos would probably reduce how frequently they would need to redo experiments. Since the students are willing to implement this solution, we as a team feel more confident recommending it. We know that these videos would take time and effort to produce but could be beneficial for the chemistry department moving forward.

There are a few limitations with implementing this into introductory lab courses. During our instructor/TA survey, a chemistry TA brought up the issue of making mistakes and how important it is. Making mistakes in the lab is an important part of the curriculum and using these tutorials may take away from this. However, this would only be an issue if the videos are produced incorrectly. Since the professors explain the experiment during the beginning of lecture, they are giving more information that would be needed to produce these tutorials. The explanations in the lab section are much more specific than what would be needed since the videos would be kept very general. In addition to this, this could also prevent students from having the opportunity to research this before the lab period. This issue can be avoided if the videos are shown after pre-lab submission. This way, the videos would not interfere with the initial research.

The bigger issue is that the solution would not be as effective for the biology teaching laboratories. According to our Professor/TA survey, the biology labs already have video tutorials for most experiments. In addition, the support among students, according to our student survey, was below 50% for biology labs. In our lab observations, it was noted that most biology students exhibited proper waste disposal and waste reductio methods compared to students taking chemistry courses. This is why we are only recommending it for chemistry laboratory courses, but still encourage the implementation of them into any introductory biology courses that do not have them.

5.3.5 Waste Reduction Instruction

Instruction on waste reduction in the lab would involve putting a greater emphasis on waste reduction in WPI's introductory chemistry and biology labs. It would first involve providing lectures to students at the beginning of the course that detail when it is appropriate to reuse items in the lab and how to properly dispose of non-hazardous and hazardous waste. The lectures can also give general tips on how students can reduce waste throughout the course. Finally, the lectures can explain the negative impacts of lab waste to motivate students to reduce as much material waste as possible. These lectures can be delivered in a video format, or they may be in-person lectures given during class. They could be given alongside any lab safety lectures students need to watch or attend.

The lectures should be created by the instructor of each lab course to ensure accuracy and reflect the course curriculum. In addition to these lectures, during each lab class the instructor and TA should go over any specific strategies students can implement in the lab that day to reduce their waste. They should also tell students roughly how much of each chemical and material students should be using during the period to prevent them from using an excess amount. Waste reduction instruction has been implemented by other research groups and colleges. Researchers at a college monitored the volume of chemicals students spilled before and after they were informed of the impacts their spilled waste could have (Tsokou et al., 2019). The researchers saw a 50% reduction in volume spilled after the educational approach. Laboratory instruction and explanation of the impact of lab waste in an introductory lab class can motivate students to reduce excessive lab waste, such as that caused by chemical spillage.

To our knowledge from having taken introductory chemistry and biology courses, there is no introductory information on waste reduction. Across all our lab observations, we also have not seen examples of instructors or teaching assistants giving students instruction on how to reduce lab waste or explaining the impacts of lab waste. During our CH1010 observations, some of the instructors gave students brief outlines on the amount of chemical needed for the lab procedure and the proper waste disposal method. Other observations we made include instances where students would use DI water when tap water would have been acceptable, students would dispose the DI to refill new volumes when they could have reused this water, and students would use multiple pipette tips when they could have reused a singular pipette tip throughout the experiment. These reduction practices were confirmed by instructors and would not have compromised results or the integrity of their lab.

Implementing the waste reduction instruction will take time and effort in producing quality lectures. Providing waste reduction instruction during the class period could limit the time students have to conduct their experiments. However, this can be solved by distributing the instruction in the form of a video lecture or in a text format before class. From our student surveys, over 75% of respondents said they would be in favor of implementing waste reduction instruction for the introductory chemistry labs and around 50% said the same for biology labs. The waste reduction instruction can provide general tips on how students can reduce waste throughout the course, detail when it is appropriate to reuse items in the lab, and how to properly dispose of non-hazardous and hazardous waste.

5.4 Our Purchasing System Solutions

Throughout this project, there has been a disconnect in the purchasing data available between the chemistry and biology departments. This disconnect makes it difficult to assess the issue of waste disposal at WPI. For the purchasing data and interviews conducted surrounding this, the Chemistry and Biology Departments need to be made aware of how much they have purchased in the past and continue to buy in bulk, resulting in a lot of excess items, such as gloves. The issue with the number of gloves purchased is that it contributes to the amount of waste disposed of in laboratory courses. They are the most disposed of items from laboratory courses, which the laboratory professors have confirmed. In addition, the purchasing data for the chemistry department said we were not allowed access to specific data, specifically liquid waste, throughout the process of this project, which made it very difficult to assess our initial goal.

When presented with solutions for easier access to records for the departments, Procurement either said the operations were not feasible or that the purchasing system already contained those parameters. When trying to collaborate with the chemistry and biochemistry departments regarding our professor and TA survey, we were told that they did not wish to participate in our survey. While some staff members of these departments have expressed concern or interest in solving the problem of excess waste produced at WPI, many general staff members are too busy to address it, as WPI does not have a team focused on laboratory sustainability on campus.

The purchasing system contains purchasing information on inventory, such as the quantity of items for each purchase, the price, and the catalog number of every item purchased. However, the procurement system does not collect information that will allow items to be searched by specific criteria (i.e., the type of material each item is made of). In the absence of the ability to sort purchased items by material, items have to be individually searched by catalog number or from someone with expertise in individual purchases (i.e., biology and chemistry purchasing managers and the company's technical product support service). Practical changes can be implemented to the structure of the purchasing system that will collect information in an assessable form.

To account for the intake of laboratory materials, there is an opportunity to identify the classifying information at the stage of purchasing. While setting up a Purchase Step, a dropdown can be included to allow the buyer to select a category for purchasing laboratory materials, including disposable plastics, disposable glass, chemicals, gloves, or non-disposables. Further classification of the item(s) being purchased will allow the data to be informative and create purchasing records that can be sorted into specific criteria. While setting up a purchase step, there can be a dropdown option specifying which department is purchasing the item(s). While the department making a purchase may have been identified, the further specification will allow records to be convenient and improve the accessibility for faculty in each department.

In the Spend Category Section, Procurement can include a "Reason for Purchase" section. This will encourage buyers to consider why items are needed and hopefully introduce more sustainable practices. In addition, when the data is compiled into Excel sheets, categories can be generated to sort the orders by the department that made the purchase and the product type. This allows faculty or students to analyze purchases based on specific criteria as a multitude rather than searching through records for each individual purchase. It is also beneficial to consider group purchasing organizations to purchase supplies in bulk, reduce the amount of packaging, solicit the best financial option for products, and incorporate sustainable habits.

The current Workday system does not allow changes or customization to certain features within the purchasing system, which limits recommendations previously mentioned. In addition, the Workday system does not contain memory features that would allow information and subcategories to populate, such as Chemical Abstracts Service (CAS) numbers. Throughout this project, the Procurement Office has been very cooperative, as they are receptive to our recommendations and have taken our solutions into consideration. Since WPI does not have a team focused on laboratory sustainability, we recommend establishing a separate team dedicated to sustainability of labs on campus and encourage collaboration between the Office of Sustainability and the Procurement Office. Although the purchasing system is structured for financial and budgeting purposes, implementing these changes could make the purchasing system more informative for WPI faculty and student projects such as this Green Labs IQP project.

5.5 Concluding Remarks

The Green Labs project aims to reduce the environmental impact of laboratories at Worcester Polytechnic Institute by assessing the contributing factors of laboratory waste and fostering a culture of sustainability that embraces WPI's innovative practices. This project evaluated the current waste management and purchasing system to determine possible refinements that will make information accessible to the WPI community. We provided solutions based on the amount of single-use plastics, single-use glass, and other lab commodities generated within WPI's instructional labs for the academic years between 2019 to 2022. A shift in how research is conducted and supported is necessary to help reduce our environmental impact on campus. Providing alternatives, acknowledging sources of emissions, and spreading awareness of the environmental impacts of a lab can promote green lab practices. The project supports sustainability efforts at WPI by providing a comprehensive overview of the amount of material waste generated in undergraduate Biology and Chemistry instructional labs. The Green Labs project hopes to embed a culture of sustainability within Worcester Polytechnic Institute laboratories to reduce the environmental impact of our research and education.

References

Addgene. (2018, March 19). Pipette tip spreader [YouTube Video]. In *YouTube*. https://www.youtube.com/watch?v=3NHq_rkwU64

American Society of Civil Engineers. (2017, January 17). *Wastewater*. 2021 Report Card for America's Infrastructure. https://infrastructurereportcard.org/cat-item/wastewater-infrastructure

Bhanot. D. (2016, December 6). Deciding between glass and plastic laboratory ware. Lab-Training.com. https://lab-training.com/deciding-glass-plastic-laboratory-ware

Campus Race to Zero Waste. (n.d.). Retrieved February 16, 2023, from https://campusracetozerowaste.org/

Canesi, L., & Fabbri, E. (2015). Environmental Effects of BPA: Focus on Aquatic Species. *Dose-response: a publication of International Hormesis Society, 13*(3), 1559325815598304. https://doi.org/10.1177/1559325815598304

Case Western Reserve University Environmental Health and Safety. (n.d.). *Disposing of Solid Wastes*. Retrieved February 20, 2023, from https://case.edu/ehs/waste-disposal/solid-wastemunicipal-waste/disposing-solid-wastes

Center for Disease Control. (2005, September 16). *Improper disposal of hazardous substances and resulting injuries - Selected states, January 2001-March 2005*. Morbidity and Mortality Weekly Report. https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5436a2.htm

Chen, D. M.-C., Bodirsky, B. L., Krueger, T., Mishra, A., & Popp, A. (2020). The world's growing municipal solid waste: trends and impacts. *Environmental Research Letters, 15* , 074021. https://doi.org/10.1088/1748-9326/ab8659

Cornell Law School. (n.d.). *33 CFR § 151.05 - Definitions*. Legal Information Institute. Retrieved February 16, 2023, from https://www.law.cornell.edu/cfr/text/33/151.05

Croston, L. (2012, May 4). *Considerations for glass to plastic labware conversion*. American Laboratory. https://www.americanlaboratory.com/914-Application-Notes/111807-Considerations-for-Glass-to-Plastic-Labware-Conversion

Domingo, J. L., Marquès, M., Mari, M., & Schuhmacher, M. (2020). Adverse health effects for populations living near waste incinerators with special attention to hazardous waste incinerators. A review of the scientific literature. *Environmental Research, 187*, 109631. https://doi.org/https://doi.org/10.1016/j.envres.2020.109631

Eppendorf. (n.d.). Retrieved February 16, 2023, from https://www.eppendorf.com/US-en/

Express Clear Solutions. (2019, February 11). *What happens when water goes down the drain*? https://expressclear.co.uk/resources/environment/what-happens-when-water-goes-down-the-drain

Folino, A., Karageorgiou, A., Calabrò, P. S., & Komilis, D.. (2020). Biodegradation of wasted bioplastics in natural and industrial environments: A review. *Sustainability, 12*(15), 6030. https://doi.org/10.3390/su12156030

García-Pérez, J., Fernández-Navarro, P., Castelló, A., López-Cima, M. F., Ramis, R., Boldo, E., & López-Abente, G. (2013). Cancer mortality in towns in the vicinity of incinerators and installations for the recovery or disposal of hazardous waste. *Environment International, 51*, 31-44. https://doi.org/https://doi.org/10.1016/j.envint.2012.10.003

Hemani, D., Hostetter, C., & Bagley, M. (2018, June 20). *Don't waste the medical waste: Reducing improperly classified hazardous waste in a medical facility*. Journal of Emerging Investigators. https://emerginginvestigators.org/articles/don-t-waste-the-medical-waste-reducing-improperly-classified-hazardous-waste-in-a-medical-facility

Indiana University Center for Postsecondary Research (2021). *Carnegie Classifications 2021 public data file,* http://carnegieclassifications.acenet.edu/downloads/CCIHE2021-PublicDataFile.xlsx

Jacoby, M. (2019). *The state of glass recycling in the US*. Chemical & Engineering News. https://cen.acs.org/materials/inorganic-chemistry/glass-recycling-US-broken/97/i6

Kellogg, K. (2019, September 13). *Glass or plastic: Which is better for the environment?* Going Zero Waste. https://www.goingzerowaste.com/blog/which-is-better-for-the-environment-glass-or-plastic

Kemsley, J. N. (2009, March 9). *Where lab waste goes*. Chemical & Engineering News; American Chemical Society. https://cen.acs.org/articles/87/i10/Lab-Waste-Goes.html

Kidersley, D. (2020, January 29). *Understand how distillation works*. ThoughtCo. https://www.thoughtco.com/what-is-distillation-601964

Kõrgmaa, V., Laht, M., Rebane, R., Lember, E., Pachel, K., Kriipsalu, M., Tenno, T., & Iital, A. (2020). Removal of hazardous substances in municipal wastewater treatment plants. *Water Science and Technology, 81*(9), 2011-2022. https://doi.org/10.2166/wst.2020.264

Landfills in Virginia. (n.d.). Virginiaplaces.org. http://www.virginiaplaces.org/waste/landfill.html

Lim, X. (2021). Microplastics are everywhere — but are they harmful? *Nature, 593*(7857), 22–25. https://doi.org/10.1038/d41586-021-01143-3

McGill University. (2015, March). *SP0131: Laboratory sustainability initiative*. McGill Sustainability. https://www.mcgill.ca/sustainability/sp0131-laboratory-sustainability-initiative

Mountain States Environmental Services. (n.d.). Retrieved February 16, 2023, from https://www.mountainstatesenvironmental.com

My Green Lab. (2022). *Water*. https://www.mygreenlab.org/water.html

My Green Lab. (n.d.). Retrieved February 16, 2023, from https://www.mygreenlab.org

National Research Council. (1989). *Biosafety in the laboratory: Prudent practices for the handling and disposal of infectious materials*. National Academies Press (US).

Paradise, A. (2019, March). *Clinical labs: making the switch to green.* AACC. https://www.aacc.org/cln/articles/2019/march/clinical-labs-making-the-switch-to-green

Pesimo, A. (2014). Developing the learning outcomes of the students through microscale experiments in chemistry. *OALib, 01,* 1-11. https://doi.org/10.4236/oalib.1100479

Queensland Government. (2017). *Sulfur dioxide*. https://www.qld.gov.au/environment/management/monitoring/air/air-pollution/pollutants/sulfur-dioxide

Relph, R. (2020, April 1). *Making sustainable labs a reality*. Lab Manager. https://www.labmanager.com/business-management/making-sustainable-labs-a-reality-22090

Reynolds, M. C., Finn, D., Sarno, A. F., Allen, R., Deathrage, J. D., Krajmalnik-Brown, R., & Cadillo-Quiroz, H. (2022). Delineating the Drivers and Functionality of Methanogenic Niches within an Arid Landfill. *Applied and Environmental Microbiology, 88*(9), e0243821. https://doi.org/10.1128/aem.02438-21

Rochman, C. M., Browne, M. A., Halpern, B. S., Hentschel, B. T., Hoh, E., Karapanagioti, H. K., Rios-Mendoza, L. M., Takada, H., Teh, S., & Thompson, R. C. (2013). Classify plastic waste as hazardous. *Nature, 494*(7436), 169-171. https://doi.org/10.1038/494169a

Sanghi, R., & Singh, V. (2012). Green bio-energy sources. In *Green chemistry for environmental remediation* (pp. 425–626). essay, Scrivener Pub.

Silva, A. L. P., Prata, J. C., Duarte, A. C., Soares, A. M. V. M., Barceló, D., & Rocha-Santos, T. (2021). Microplastics in landfill leachates: The need for reconnaissance studies and remediation technologies. *Case Studies in Chemical and Environmental Engineering, 3,* 100072. https://doi.org/10.1016/j.cscee.2020.100072

Stanford Environmental Health & Safety. (n.d.). *List of non-hazardous chemical waste*. Stanford University. Retrieved February 16, 2023, from https://ehs.stanford.edu/reference/list-non-hazardous-chemical-wastes

Strategic Materials. (n.d.). Capabilities. Retrieved February 20, 2023, from https://www.smi.com/capabilities/

Tabone, M. D., Cregg, J. J., Beckman, E. J., & Landis, A. E. (2010). Sustainability metrics: Life cycle assessment and green design in polymers. *Environmental Science & Technology*, *44*(21), 8264–8269. https://doi.org/10.1021/es101640n

TerraCycle. (n.d.). Retrieved February 16, 2023, from https://www.terracycle.com/en-US

Teuten, E. L., Saquing, J. M., Knappe, D. R. U., Barlaz, M. A., Jonsson, S., Björn, A., Rowland, S. J., Thompson, R. C., Galloway, T. S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Viet, P. H., Tana, T. S., Prudente, M., Boonyatumanond, R., Zakaria, M. P., Akkhavong, K., … Takada, H. (2009). Transport and release of chemicals from plastics to the environment and to wildlife. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1526), 2027–2045. https://doi.org/10.1098/rstb.2008.0284

Thompson, J., & Watson, R. (2018, May 4). *Time is running out: The U.S. landfill capacity crisis*. SWEEP. https://sweepstandard.org/time-is-running-out-the-u-s-landfill-capacity-crisis

Tsokou, A. M., Howells, A., & Stark, M. S. (2019). Measuring and reducing chemical spills by students: A randomized controlled trial of providing feedback. *Journal of Chemical Education*, *96*(10), 2180–2187. https://doi.org/10.1021/acs.jchemed.9b00262

United Nations Educational, Scientific and Cultural Organization. (2015, November 4). *Facts and figures: human resources*. https://en.unesco.org/node/252277

United Nations Statistics Division. (2013). *Environmental glossary*. https://unstats.un.org/unsd/environmentgl/gesform.asp?getitem=1178

United States Census Bureau. (2014, July 10). *Where do college graduates work?* https://www.census.gov/dataviz/visualizations/stem/stem-html

United States Environmental Protection Agency. (2015, November 25). Learn the basics of hazardous waste. https://www.epa.gov/hw/learn-basics-hazardous-waste

United States Environmental Protection Agency. (2015, November 25). *Defining hazardous waste: Listed, characteristic and mixed radiological wastes*. https://www.epa.gov/hw/defining-hazardous-waste-listed-characteristic-and-mixed-radiological-wastes

United States Environmental Protection Agency. (2016, January 12). *Greenhouse gas emissions from a typical passenger vehicle*. https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle

United States Environmental Protection Agency. (2017, September 7). Glass: Material-specific data. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/glass-material-specific-data

University of Colorado Boulder. (n.d.). *Proper use of Pasteur pipets*. Organic Chemistry at CU Boulder. Retrieved February 16, 2023, from https://www.orgchemboulder.com/Technique/Procedures/Pipets/Pipets.shtml

University of Colorado Denver. (2016, April 27). *Recycling waste acetone at teaching laboratories*. CU Denver News. https://news.ucdenver.edu/recycling-waste-acetone-teaching-laboratories

University of Pennsylvania. (2022, September 30). *Biohazardous waste*. PennEHRS. https://ehrs.upenn.edu/health-safety/regulated-waste/biohazardous-waste

Urbina, M. A., Watts, A. J. R., & Reardon, E. E. (2015). Labs should cut plastic waste too. *Nature*, *528*(7583), 479-479. https://doi.org/10.1038/528479c

Varshney, R., Singh, P., & Yadav, D. (2022). Chapter 2 - Hazardous wastes treatment, storage, and disposal facilities. In D. Yadav, P. Kumar, P. Singh, & D. A. Vallero (Eds.), *Hazardous waste management* (pp. 33-64). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-824344-2.00009-4

Vasarhelyi, K. (2021, April 15). *The hidden damage of landfills*. Environmental Center. https://www.colorado.edu/ecenter/2021/04/15/hidden-damage-landfills

Weires, N. A., Johnston, A., Warner, D. L., Mccormick, M. M., Hammond, K., & Mcdougal, O. M.. (2011). Recycling of waste acetone by fractional distillation. *Journal of Chemical Education*, *88*(12), 1724–1726. https://doi.org/10.1021/ed2001158

Wirsig, K. (2022, March 18). *Burning plastic is a terrible idea. Here's why*. Environmental Defence. https://environmentaldefence.ca/2022/03/18/burning-plastic-is-a-terrible-idea

World Bank. (1998). Glass Manufacturing. In *Pollution prevention and abatement handbook* (pp. 320–323).

World Health Organization. (2016, October 4). *Dioxins and their effects on human health*. https://www.who.int/news-room/fact-sheets/detail/dioxins-and-their-effects-on-human-health

Zawartka, P., Burchart-Korol, D., & Blaut, A. (2020). Model of carbon footprint assessment for the life cycle of the system of wastewater collection, *Transport and Treatment. Scientific Reports, 10* . https://doi.org/10.1038/s41598-020-62798-y

Zhang, J. (2010, December 10). *UC Berkley water usage & conservation study report*. Chancellor's Advisory Committee on Sustainability. http://sustainability.berkeley.edu/sites/default/files/UC_BERKELEY_WATER_CONSERVATION_REPORT_CACS_2010.pdf

Zimmermann, L., Dombrowski, A., Völker, C., & Wagner, M. (2020). Are bioplastics and plant-based materials safer than conventional plastics? In vitro toxicity and chemical composition. *Environment International, 145,* 106066. https://doi.org/https://doi.org/10.1016/j.envint.2020.106066

Appendix A: Glossary

Term	Definition
BB2915	The abbreviation for the "Solutions In Soil" WPI class. In this class, students would grow bacteria from soil. Students would test the bacteria they grew for antibacterial properties.
CH1010	The abbreviation for WPI's introductory chemistry course. This is the first general chemistry course students generally take. In this course, students learn basic chemistry lab skills and perform common experiments.
CH1020	The abbreviation for WPI's second chemistry course. This course is usually taken after CH1010 and builds upon CH1010's lessons.
Chemical waste	Any solid, liquid, or gaseous waste that can be hazardous or non-hazardous. These are typically purified or artificial substances like elements, purified acids, or chemical compounds.
Gateway Park	The building WPI uses for graduate and academic research. It is a large and advanced laboratory building that contains several academic research programs.
Goddard Hall	The on-campus building that contains several labs for undergraduate students to use. Often these labs are used for classes rather than research. It is the home of the chemistry, biochemistry, and chemical engineering departments.
Hazardous chemical waste	Chemical waste that needs special treatment before they are disposed of. If hazardous waste is improperly disposed, it can cause significant harm to the environment and/or living organisms. They usually have one or more of the following traits: toxicity, corrosivity, reactivity, and ignitability.
Material waste	This term refers to all of the waste within the scope of this project, excluding chemicals. This includes disposable plastic, glass, gloves, and rubber.
Non-hazardous chemical waste	Chemical waste that does not pose a significant threat to life or the environment. Examples include salt and non-reactive metals.
P-Card	A P-card is essentially a credit card that faculty/staff can use to purchase required lab materials. It is used for purchases outside of WPI's approved vendors. When a purchase is made using a P-card, only budgeting information is recorded. This means the identity of the item is not recorded.

Qualtrics	An online program that can be used to create surveys.
STARS	The old program WPI used for purchases. The information it recorded is exactly the same as the current system.
WPI’s Procurement Office	The administrative office that provides oversight and guidance for the purchase of goods and services at WPI. Procurement is in charge of developing purchasing policies and monitors compliance.
WPI’s Purchasing system	The overall system WPI uses to purchase lab materials. Faculty/staff who want to purchase supplies will login to Workday and select an item from WPI’s preferred vendors. Once an item is selected, information about that item is automatically recorded, but some things need to be manually added. Once a purchase is complete, the information about the purchase is logged into an Excel spreadsheet that Procurement oversees.
Workday	The all-purpose online program WPI uses. Students register for courses through Workday, as well as viewing their schedueles and finances. Workday is also used as a medium to purchase lab materials and office supplies.

Appendix B: Analysis Procedure of Biology Purchasing Data

This appendix section gives an overview on what exactly the biology purchasing data is, and how we analyzed it.

The Data Set

We got our data set the biology lab manager, Mihail Bocka, who was able to get it from WPI's Procurement Office. The data set included all purchases made by members of WPI's Biology & Biotechnology department through Workday, STARS, or P-Cards since October 2018. Workday is WPI's current online purchasing system, while STARS is its predecessor.

The information the data set gave for the Workday and STARS purchases is different than that for the P-Card purchases. For the former, the data set gave the manufacturer's name, the item's catalog number, and the total quantity of that catalog number ordered. The latter completely lacked this information. For this reason, we were unable to perform any analysis on the P-Card data. The section below details our analysis on just the Workday and STARS data.

How We Analyzed

In our analysis, we only considered orders made after 2018, as this gave us four complete years of purchasing data. We also only considered orders made by Mihail Bocka, since he does all the purchasing for the biology labs in Goddard Hall. These labs encompass all but a few of WPI's biology teaching labs, and some student project labs.

To begin our analysis, we manually searched manufacturer websites for each order's catalog number, and noted what each item was. Each item was either a chemical, a piece of labware, an instrument, or some service (e.g., pipette calibration). We only concerned ourselves with the chemical and labware items.

For chemical items, we wrote what type of chemical it was using Table A1. We also noted the chemical's mass (if it was a solid) or volume (if it was a liquid, liquid solution, or pressurized gas).

For labware items, we noted their type using Table A2, and the number of individual items included in each order. We also noted what material they were made of, and if it they were disposable. We considered disposable items to be those that could not, or would not, be reused numerous times. To determine which items were disposable, we used the information provided by the manufacturer and our knowledge of how each are used in WPI's biology teaching labs.

Table B1. All categories of chemical items we used during our analysis of the biology purchasing data.

Chemical Type	Definition
Antimicrobial	Any sort of antimicrobial
Buffer	Any sort of pre-made buffer solution
Buffer solid	Solid form of the pH active buffer component
Chelator	Any chelating agent, like EDTA
Column packing	Stationary phase to be used in some chromatography column
Culture media	Media for cell culture
Disinfectant	Any sort of disinfectant, including bleach
Dye	Any dye or stain
Effector	Any effector molecule (inhibitor, activator, etc.), not including proteins or lipids
Endotoxin	Any sort of endotoxin, like a lipopolysaccharide
Gelatin	Any sort of gel/gelatin
Inorganic salt	Any inorganic salt, like NaCl
Lipid	Any sort of lipid
Liquid nitrogen	Liquid nitrogen in any form
Organic solvent	Any type of organic solvent
Polymer	Any sort of abiotic polymer not classified as any other type
Protein	Any protein or amino acid
Reagent	Some sort of reagent destined for a chemical reaction. Also includes assay solutions
Safe gas	Safe, non-hazardous gas. Will come in a pressurized cylinder
Soap	Any sort of soap, including antimicrobial soap

Table B2. All categories of labware items we used during our analysis of the biology purchasing data.

Labware Type	Definition
1000mL beakers	Any sort of 1L beaker
10mL serological pipettes	10mL serological or graduated pipettes of any form
150mL filters	Any vacuum filtering unit designed for 150mL
15mL centrifuge tubes	15mL centrifuge tubes of any form
1mL serological pipettes	1mL serological or graduated pipettes of any form
1mL syringes	Any syringe 1mL in volume
250mL bottles	Any sort of storage bottle with maximum volume of 250mL
250mL culture flasks	Any sort of cell culture flask 250mL in volume
250mL filters	Any vacuum filtering unit designed for 250mL
25mL serological pipettes	25mL serological or graduated pipettes of any form
2mL serological pipettes	2mL serological or graduated pipettes of any form
3mL syringes	Any syringe 3mL in volume
500mL bottles	Any sort of storage bottle with maximum volume of 500mL
500mL filters	Any vacuum filtering unit designed for 500mL
50mL centrifuge tubes	50mL centrifuge tubes of any form
50mL culture flasks	Any sort of cell culture flask 50mL in volume
50mL filters	Any vacuum filtering unit designed for 50mL
50mL serological pipettes	50mL serological or graduated pipettes of any form
5mL column	Any sort of chromatography column that's 5mL in volume
5mL serological pipettes	5mL serological or graduated pipettes of any form
5mL syringes	Any syringe 5mL in volume
6mL protein concentrators	Any protein concentrator with a maximum input of 6mL
Bags	Small bags, mainly Ziploc sandwich bags
Cover slips	Any type of slip put over microscope sample
Cup	Some sort of cup, like those you'd drink out of

Cuvettes	Cuvettes of any size or material
Dialysis membranes	Any sort of dialysis membrane or dialysis tubing
Disposable gloves (SIZE)	Disposal gloves of the indicated size, where L = large, M = medium, etc.
Disposable scalpels	Some sort of single use scalpel or blade
Inoculating loops	Any sort of inoculating loop
Large microcentrifuge tubes	Any microcentrifuge or Eppendorf tube 1mL or greater in volume
Large vials	Any sort of large vial, meaning a maximum volume greater than 5mL
Microscope slides	Any form of microscope slide
n/a	Any piece of labware that is clearly highly reusable, like micropipettes
Pasteur pipettes	Any sort of Pasteur pipette, including droppers
Petri dishes	Petri dishes of any form
Pipette tips	Pipette tips of any size
Plastic wrap	Plastic wrap in any form
Plate covers	Any cover slip meant to be put over well plate
Small membranes	Any small, stand-alone membrane
Small microcentrifuge tubes	Any microcentrifuge or Eppendorf tube less than 1mL in volume
Small vials	Any sort of small vial, meaning a maximum volume of 5mL or less
Syringe filters	Any small filter apparatus that goes on syringe end
Test tube caps	Any sort of cap for a test tube
Test tubes	Any sort of test tube
Weigh surfaces	Weigh paper or boats
Well plates	Well plates of any size or form

Once we finished sorting all the chemical and labware items, we found the total amount of each purchased each year since 2019. While doing this, we noticed a few orders still hadn't arrived yet. Since all of these were ordered at least over a month ago, we ignored them when counting totals. We also noticed a few orders that only partially arrived, meaning some of their items were supposedly still being shipped. Since all of these were also ordered over a month ago, we did not consider the items that hadn't arrived yet when making the totals.

When totaling each chemical, we saw that certain categories of chemicals came in both solid and liquid formats. For example, a protein could come as a solid powder or aqueous solution. For chemicals like this, we therefore had to separate their totals into the amount of solid and liquid chemical bought.

When totaling each piece of labware we only looked at the disposable items. Once we had their totals, we converted each into a weight using the average weight of each across all manufacturer sites we could find that listed a weight. Very few manufacturers listed the weight of their items, so most items only had one source for weight. For some items, we couldn't find a weight anywhere and had to measure it ourselves.

Once we had all of these weights, we compared them to the material the item was made of to derive the total weight of disposable plastic and glass purchased each year since 2019. When doing this, we didn't count the weight of disposable scalpels, since they contain a lot of metal in addition to their plastic handle. Doing this should not have greatly impacted the data, since the labs only bought 20 disposable scalpels total.

One thing to consider is that most chemicals the labs bought came in some sort of disposable plastic container. No manufacturer provided any information about the weight or dimensions of these containers, so it was impossible for us to quantify them in any way. Based on how many chemicals the labs bought, counting these containers in our totals for disposable plastics would likely boost the numbers by a lot.

Later in our analysis, we acquired the total number of students enrolled in Goddard Hall's in-person biology labs each. To do this, we used Workday's course records (WPI also uses Workday for course registration). These records list each course section's name, description, and number of students. However, the sections before A term (the first half of fall semester) of 2021 did not list if the course is a lab, or where the course took place. For these courses, we assumed that if they were listed as a Goddard Hall lab in future years, they remained so in these earlier years. Workday still listed if these older courses were in-person or online.

Appendix C: Raw Purchasing Data

The Excel spreadsheet linked below contains the raw data we used to make our figures and tables for the biology purchasing data (i.e., Figure 4.4E-4.4P). This data is located across the sheet in various tables beside their respective figure. We unfortunately were not permitted to publish the same data for our chemistry purchasing figures.

https://1drv.ms/x/s!AsvIpoyH0oqNah-EkEZZIB9IKZA?e=VBUvJa

Appendix D: Questions for Procurement

Below lists the exact questions we asked WPI's Procurement Office. We sent these questions over email.

1. Does Procurement keep a record of the purchasing orders made to stock the teaching labs in Goddard Hall?
    a. *Most of our questions assume this is, at least to some degree, true.*
2. What information is noted for each order in these records?
    a. Is the reason for the purchase recorded?
        i. For example, is it noted what specific lab classes the ordered product will be used for?
    b. Is any descriptive information about the product beyond its catalog number noted in the records?
        i. For example, what material the product is made of, or its total weight?
        ii. Can this descriptive information be recorded with the current purchasing software?
            1. If so, would the information be captured automatically or input by the purchaser?
3. When purchasing research supplies, most products will fall within the "Laboratory Supplies" spend category.
    a. Is the current purchasing software capable of expanding the "Spend Category" to differentiate between the types of "Laboratory Supplies" that are purchased?
        i. For instance, can the buyer specify if the products are Glass Laboratory Supplies, Plastic Laboratory Supplies, and/or Other Laboratory Supplies?
4. How far back do the purchasing records for the teaching labs in Goddard Hall go?
5. How easily can these purchasing records be accessed?
    a. And when accessing the records, what form do they come in?
        i. Do they exist as a spreadsheet file, a web page, etc.
6. Is it possible to sort and filter these purchasing records by various criteria?
    a. Can you sort the orders by date purchased, reason for purchase, type of product, etc.

7. When purchasing out of network, the receipt is recorded, rather than the catalog number of the item(s).
    a. Is the current purchasing system capable of getting more information, such as the catalog number, for items purchased out of network?
        i. If not, how can these records be organized to ensure the out of network records are consistent with the records of purchases made from a preferred vendor?
8. Does Procurement view its current recordkeeping systems as ideal?
    a. If not, what are the major limitations of the systems, and are there any plans to address them?

Appendix E: Student Survey Questions

Pasted below is an exported version of the full survey we sent to lab students. The questions are organized into "blocks," which correspond to each section of the survey. Questions that are only asked given some specific prior responses are noted with blue boxes above the question. The order of the questions reflects the order of the survey.

Start of Block: Qualification

Q1 Our team is conducting this survey for an IQP project focused on reducing the amount of student-generated waste in WPI's introductory chemistry and biology lab courses. Your responses will help give us a better understanding of the waste in these courses, and give us valuable feedback on our proposed solutions. *The intended audience for this survey is students who have taken in-person introductory biology or chemistry labs at WPI.*

At the end of the survey is a link to enter into a raffle for a $25 Amazon giftcard.

Your responses are anonymous and will be used as data in our IQP report. Please select the option below if you consent to this.

- Yes I consent

Q2 The following survey will take about 6 minutes. Thank you for choosing to spend your time here!

Q3 Have you taken an in-person introductory biology and/or chemistry lab at WPI? These labs include CH1010, CH1020, CH1030, and all 2000-level BB labs.

- Yes
- No

End of Block: Qualification

Start of Block: Demographics

Q3 What grade level best describes you?

- Freshman
- Sophomore
- Junior
- Senior
- Graduate

Q39 What in-person, introductory labs have you taken at WPI?

- Biology (any 2000-level BB lab)
- Chemistry (CH1010, CH1020, or CH1030)

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q41 What years did you take those introductory **biology** labs?

- 2018
- 2019
- 2020
- 2021
- 2022
- 2023

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q45 What years did you take those introductory **chemistry** labs?

- 2018
- 2019
- 2020
- 2021
- 2022
- 2023

End of Block: Demographics

Start of Block: General Opinions

Q15 How important of an issue do you think reducing lab waste is?

- Not at all important
- Slightly important
- Moderately important
- Very important
- Extremely important

Q37 Do you think WPI has sustainable, environmentally friendly practices in their introductory biology and chemistry labs?

- Definitely not
- Probably not
- Neutral/unsure
- Probably yes
- Definitely yes

Q38 Do you want WPI to have more sustainable and environmentally friendly practices in these labs?

- Definitely not
- Probably not
- Neutral/unsure
- Probably yes
- Definitely yes

End of Block: General Opinions

Start of Block: Opinions on Labs

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q4 When performing experiments in the introductory **biology** labs you've taken, how well did you usually understand the procedure?

- Not well at all
- Slightly well
- Moderately well
- Very well
- Extremely well

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q5 How often did you make experimental errors in the introductory **biology** labs you've taken?

- Very infrequently
- Somewhat infrequently
- Unsure
- Somewhat frequently
- Very frequently

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q6 In the introductory **biology** labs you've taken, how often did you need to redo experiments for preventable reasons?

- Never
- Sometimes
- About half the time
- Most of the time
- Always

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q51 In the introductory **biology** labs you've taken, how often were you confused on where to put your waste?

- Very infrequently
- Somewhat infrequently
- Unsure
- Somewhat frequently
- Very frequently

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q48 When performing experiments in the introductory **chemistry** labs you've taken, how well did you usually understand the procedure?

- Not well at all
- Slightly well
- Moderately well
- Very well
- Extremely well

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q49 How often did you make experimental errors in the introductory **chemistry** labs you've taken?

- Very infrequently
- Somewhat infrequently
- Somewhat frequently
- Very frequently

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q50 In the introductory **chemistry** labs you've taken, how often did you need to redo experiments for preventable reasons?

- Never
- Sometimes
- About half the time
- Most of the time
- Always

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q52 In the introductory **chemistry** labs you've taken, how often were you confused on where to put your waste?

- Very infrequently
- Somewhat infrequently
- Unsure
- Somewhat frequently
- Very frequently

Q16 In the following section, you'll be presented with four ideas that aim to reduce waste in WPI's introductory biology and chemistry labs. For each idea, please give your honest opinion.

End of Block: Opinions on Labs

Start of Block: Experiment Tutorials

Q17 Solution 1 - Experiment Tutorials

After an experiment's pre-lab is due, but before class, videos are unlocked on Canvas that demonstrate how to perform the lab techniques used by the experiment. Everything is kept very general in the videos as to not simply give the students the experiment's entire procedure. We hope these videos will decrease student error in experiments, leading to less waste.

Here is an example of an Experiment Tutorial:

(In the actual survey, there was an embedded video of an example tutorial showing how to set up a silica gel chromatography column)

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q18 Would you like if this idea was implemented for the introductory **biology** labs you've taken?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q53 Would you like if this idea was implemented for the introductory **chemistry** labs you've taken?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q20 If this idea was implemented in the introductory **biology** labs you've taken, would it have helped you make less errors in your experiments?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q54 If this idea was implemented in the introductory **chemistry** labs you've taken, would it have helped you make less errors in your experiments?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q21 If this idea was implemented in the introductory **biology** labs you've taken, would it have reduced how often you needed to redo experiments for avoidable reasons?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q55 If this idea was implemented in the introductory **chemistry** labs you've taken, would it have reduced how often you needed to redo experiments for avoidable reasons?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Q22 (Optional) If you have additional thoughts on this idea, please write them here.

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End of Block: Experiment Tutorials

Start of Block: Incentivization Programs

Q28 Solution 2 - Incentivization Programs

Programs are developed in which students are given rewards (e.g., gift cards) for using less materials and reagents in experiments. This could involve all students getting a reward if the class as a whole doesn't exceed some waste threshold, or only the most efficient students could be given rewards.

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q29 Would you like if this idea was implemented in the introductory **biology** labs you've taken?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q56 Would you like if this idea was implemented in the introductory **chemistry** labs you've taken?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q30 If this idea was implemented in the introductory **biology** labs you've taken, would it have helped you reduce your waste output?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q57 If this idea was implemented in the introductory **chemistry** labs you've taken, would it have helped you reduce your waste output?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Q32 (Optional) If you have additional thoughts on this idea, please write them here.

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End of Block: Incentivization Programs

Start of Block: Waste Reduction Instruction

Q23 Solution 3 - Waste Reduction Instruction

At the start of the lab course, lectures are provided that explain how to reduce waste. For example, they could detail when it is okay to reuse something, explain how to ensure you don't take more than you need of some reagent, etc. Each lab, instructors or TAs also tell students roughly how much of each material/reagent they should be using, and any tips to use less. Instructors or TAs may also inform students on the impact of generating excess waste to provide them with greater motivation.

Here is an example of micropipette waste reduction instruction that could be part of a brief slideshow:

(In the actual survey, there was an embedded image giving an overview of how to reduce how many pipette tips you use while creating stock solutions)

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q24 Would you like if this idea was implemented in the introductory **biology** labs you've taken?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q58 Would you like if this idea was implemented in the introductory **chemistry** labs you've taken?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q25 If this idea was implemented in the introductory **biology** labs you've taken, would it have helped you reduce your waste output?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q59 If this idea was implemented in the introductory **chemistry** labs you've taken, would it have helped you reduce your waste output?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Q27 (Optional) If you have additional thoughts on this idea, please write them here.

____

____

____

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____

End of Block: Waste Reduction Instruction

Start of Block: Waste Disposal Posters

Q33 Solution 4 - Waste Disposal Posters

Posters are hung in the lab classrooms that outline which container each possible piece of waste should go in. While this may not reduce the actual amount of waste students generated, we hope these posters will ensure waste is always placed in the right container.

Here is an example of a waste disposal poster:

(In the actual survey, there was an imbedded image of a generic waste disposal poster)

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q34 Would you like if this idea was implemented in the introductory **biology** labs you've taken?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q60 Would you like if this idea was implemented in the introductory **chemistry** labs you've taken?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Biology (any 2000-level BB lab)

Q35 If this idea was implemented in the introductory **biology** labs you've taken, would it have helped you dispose of waste properly?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Display This Question:

If What in-person, introductory labs have you taken at WPI? = Chemistry (CH1010, CH1020, or CH1030)

Q61 If this idea was implemented in the introductory **biology** labs you've taken, would it have helped you dispose of waste properly?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Q36 (Optional) If you have additional thoughts on this idea, please write them here.

____

____

____

____

End of Block: Waste Disposal Posters

Start of Block: Raffle

Q44 Please follow the link below to enter into the raffle for the $25 Amazon giftcard.

(In the actual survey, there was a link here to enter the raffle)

Appendix F: Instructor & TA Survey Questions

Pasted below is an exported version of the full survey we sent to lab instructors and teaching assistants (TAs). The questions are organized into “blocks,” which correspond to each section of the survey. Questions that are only asked given some specific prior responses are noted with blue boxes above the question. The order of the questions reflects the order of the survey.

Start of Block: Introduction and Consent

Q1 Our team is conducting this survey for an IQP project focused on reducing the amount of student-generated waste in WPI's (in-person) introductory chemistry and biology lab courses. Your responses will help give us a better understanding of the waste in these courses, and give us valuable feedback on our proposed solutions. *The intended audience for this survey is current or former instructors and TAs of these courses*. This survey should take around 10 minutes to complete.

Your responses are anonymous and will be used as data in our IQP report. Please select the box below if you consent to this.

- Yes I consent

End of Block: Introduction and Consent

Start of Block: Background Information

Q4 Which of the following best described your position at WPI?

- Faculty
- Staff
- Post doctorate
- Graduate student
- Undergraduate student

Q5 Please select which in-person lab courses you currently teach, or have taught in the past (either as an instructor or TA).

- Any introductory chemistry lab (CH1010, CH1020, or CH1030)
- Any introductory biology lab (2000-level BB lab course)

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q6 When teaching the chemistry labs, did you serve as an instructor or TA?

- Instructor
- TA
- I have performed both roles

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q7 When teaching the biology labs, did you serve as an instructor or TA?

- Instructor
- TA
- I performed both roles

End of Block: Background Information

Start of Block: Waste Quantification

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q8 In the introductory chemistry labs you taught, how many of the listed items did students collectively throw out as waste in ONE typical class period?

	Not Applicable 0 100 200 300 400 500 600 700 800 900 1000
Pasteur pipettes	
Graduated and serological pipettes	
Micropipette tips	
Weigh paper and boats	
Centrifuge tubes	
Microcentrifuge tubes	
Plastic storage bottles	
Test tubes	
Dram vials	
Petri dishes	
Well plates	
Parafilm squares	
Disposable gloves	

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q11 In the introductory chemistry labs you taught, what volume of organic and aqueous waste did students collectively generate in ONE typical lab period?

	Volume in mL	Not Applicable
	0 1000 5000 10000	
Aqueous waste (e.g., DI water, aqueous salts)		
Organic waste (e.g., acetone, isopropanol)		

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q9 In the introductory biology labs you taught, how many of the listed items did students collectively throw out as waste in ONE typical class period?

	Not Applicable 0 100 200 300 400 500 600 700 800 900 1000
Pasteur pipettes	
Graduated and serological pipettes	
Micropipette tips	
Weigh paper and boats	
Centrifuge tubes	
Microcentrifuge tubes	
Plastic storage bottles	
Test tubes	
Dram vials	
Petri dishes	
Well plates	
Parafilm squares	
Disposable gloves	

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q12 In the introductory biology labs you taught, what volume of organic and aqueous waste did students collectively generate in ONE typical lab period?

	Volume in mL Not Applicable
	0 1000 5000 10000
Aqueous waste (e.g., DI water, aqueous salts)	
Organic waste (e.g., acetone, isopropanol)	

End of Block: Waste Quantification

Start of Block: Other Questions

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q50 How frequently do waste materials or chemicals get recycled or reused in the chemistry labs you've taught?

- Very infrequently
- Somewhat infrequently
- Unsure
- Somewhat frequently
- Very frequently

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q51 How frequently do waste materials and chemicals get recycled or reused in the biology labs you've taught?

- Very infrequently
- Somewhat infrequently
- Unsure
- Somewhat frequently
- Very frequently

Q13 Are you currently trying to implement any solutions to reduce the amount of student-generated waste in WPI's introductory lab courses?

- Yes
- No

Display This Question:

If Are you currently trying to implement any solutions to reduce the amount of student-generated was... = Yes

Q14 (Optional) Please describe the solution(s) you are trying to implement

____

End of Block: Other Questions

Start of Block: Proposed Solutions

Q16 The following section of the survey goes through our current proposed solutions to reduce the student-generated in WPI's introductory chemistry and biology lab courses.

Q17 Solution 1 - Experimental Tutorials
After an experiment's pre-lab is due, but before class, videos are unlocked on Canvas that demonstrate how to perform the lab techniques used by the experiment. Everything is kept very general in the videos as to not simply give the students the experiment's entire procedure. We hope these videos will decrease student error in experiments, leading to less waste.

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q21 How effective do you think these tutorials would be at reducing student-generated waste in the introductory chemistry labs you've taught?

- Very effective
- Somewhat effective
- Neutral/unsure
- Somewhat ineffective
- Very ineffective

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q22 What obstacles do you foresee appearing when trying to implement these tutorials in the introductory chemistry labs you've taught?

- The tutorials would negatively impact learning outcomes
- The tutorials will be difficult to produce
- The class(es) I've taught already give students adequate experimental technique demonstrations
- Other ____
- None

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q37 Overall, how likely would you be to support the implementation of these tutorials for the introductory chemistry labs you've taught?

- Very likely
- Somewhat likely
- Neutral/unsure
- Somewhat unlikely
- Very unlikely

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q31 How effective do you think these tutorials would be at reducing student-generated waste in the introductory biology labs you've taught?

- Very effective
- Somewhat effective
- Neutral/unsure
- Somewhat ineffective
- Very ineffective

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q32 What obstacles do you forsee appearing when trying to implement these tutorials in the introductory biology labs you've taught?

- The tutorials would negatively impact learning outcomes
- The tutorials will be difficult to produce
- The class(es) I've taught already give students adequate experimental technique demonstrations
- Other ____
- None

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q38 Overall, how likely would you be to support the implementation of these tutorials for the introductory biology labs you've taught?

- Very likely
- Somewhat likely
- Neutral/unsure
- Somewhat unlikely
- Very unlikely

Q48 (Optional) Please write any other feedback you have about this solution.

____

Q18 Solution 2 - Waste Reduction Instruction
At the start of the lab course, lectures are provided that explain how to reduce waste. For example, they could detail when it is okay to reuse something, explain how to ensure you don't take more than you need of some reagent, etc. Each lab, instructors or TAs also tell students roughly how much of each material/reagent they should be using, and any tips to use less. Instructors or TAs may also inform students on the impact of generating excess waste to provide them with greater motivation.

Here is an example of micropipette waste reduction instruction that could be part of a brief slideshow:

(In the actual survey, there was an imbedded image of a generic waste disposal poster)

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q23 How effective do you think this instruction would be at reducing student-generated waste in the introductory chemistry labs you've taught?

- Very effective
- Somewhat effective
- Neutral/unsure
- Somewhat ineffective
- Very ineffective

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q24 What obstacles do you foresee appearing when trying to implement this instruction in the introductory chemistry labs you've taught?

- The instruction would negatively impact learning outcomes
- The instruction will be difficult to provide
- The class(es) I've taught already give students adequate waste reduction instruction
- Other ____
- None

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q39 Overall, how likely would you be to support this instruction in the introductory chemistry labs you've taught?

- Very likely
- Somewhat likely
- Neutral/unsure
- Somewhat unlikely
- Very unlikely

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q33 How effective do you think this instruction would be at reducing student-generated waste in the introductory biology labs you've taught?

- Very effective
- Somewhat effective
- Neutral/unsure
- Somewhat ineffective
- Very ineffective

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q34 What obstacles do you foresee appearing when trying to implement this instruction in the introductory biology labs you've taught?

- The instruction would negatively impact learning outcomes
- The instruction will be difficult to provide
- The class(es) I've taught already give students adequate waste reduction instruction
- Other ____
- None

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q40 Overall, how likely would you be to support this instruction in the introductory biology labs you've taught?

- Very likely
- Somewhat likely
- Neutral/unsure
- Somewhat unlikely
- Very unlikely

Q47 (Optional) Please write any other feedback you have about this solution.

____

Q19 Solution 3 - Incentivization Programs
Programs are developed in which students are given rewards (e.g., gift cards) for using less materials and reagents in experiments. This could involve all students getting a reward if the class as a whole doesn't exceed some waste threshold, or only the most efficient students could be given rewards.

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q26 How effective do you think these programs would be at reducing student-generated waste in the introductory chemistry labs you've taught?

- Very effective
- Somewhat effective
- Neutral/unsure
- Somewhat ineffective
- Very ineffective

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q25 What obstacles do you foresee appearing when trying to implement these programs in the introductory chemistry labs you've taught?

- The students may prioritize reducing waste over properly performing the experiments
- It will be difficult to track the waste students are generating
- It will be difficult to secure funding for these rewards
- The class(es) I've taught already use programs like this
- Other ____
- None

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q41 Overall, how likely would you be to support these programs in the introductory chemistry labs you've taught?

- Very likely
- Somewhat likely
- Neutral/unsure
- Somewhat unlikely
- Very unlikely

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q35 How effective do you think these programs would be at reducing student-generated waste in the introductory biology labs you've taught?

- Very effective
- Somewhat effective
- Neutral/unsure
- Somewhat ineffective
- Very ineffective

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q36 What obstacles do you foresee appearing when trying to implement these programs in the introductory biology labs you've taught?

- The students may prioritize reducing waste over properly performing the experiments
- It will be difficult to track the waste students are generating
- It will be difficult to secure funding for these rewards
- The class(es) I've taught already use programs like this
- Other ____
- None

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q42 Overall, how likely would you be to support these programs in the introductory biology labs you've taught?

- Very likely
- Somewhat likely
- Neutral/unsure
- Somewhat unlikely
- Very unlikely

Q46 (Optional) Please write any other feedback you have about this solution.

____

Display This Question:

If What obstacles do you forsee appearing when trying to implement these programs in the introductor... = The students may prioritize reducing waste over properly performing the experiments

Or What obstacles do you forsee appearing when trying to implement these programs in the introductor... = It will be difficult to track the waste students are generating

Or What obstacles do you forsee appearing when trying to implement these programs in the introductor... = It will be difficult to secure funding for these rewards

Or What obstacles do you forsee appearing when trying to implement these programs in the introductor... = The class(es) I've taught already use programs like this

Or What obstacles do you forsee appearing when trying to implement these programs in the introductor... = Other

Or What obstacles do you forsee appearing when trying to implement these programs in the introductor... = The students may prioritize reducing waste over properly performing the experiments

Or What obstacles do you forsee appearing when trying to implement these programs in the introductor... = It will be difficult to track the waste students are generating

Or What obstacles do you forsee appearing when trying to implement these programs in the introductor... = It will be difficult to secure funding for these rewards

Or What obstacles do you forsee appearing when trying to implement these programs in the introductor... = The class(es) I've taught already use programs like this

Or What obstacles do you forsee appearing when trying to implement these programs in the introductor... = Other

Q30 Do you think the issues with the incentivization programs would be resolved if rewards were given to the lab's instructors and TAs, not the students?

- This would resolve all issues
- This would resolve some issues
- Neutral/unsure
- This would overall create more issues

Q20 Solution 4 - Waste Disposal Posters

Posters are hung in the lab classrooms that outline which container each possible piece of waste should go in. While this may not reduce the actual amount of waste students generated, we hope these posters will ensure waste is always placed in the right container.

Here is an example of a waste disposal poster:

(In the actual survey, there was an imbedded image of a generic waste disposal poster)

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q29 How effective do you think these posters would be at reducing improperly placed student-generated waste in the introductory chemistry labs you've taught?

- Very effective
- Somewhat effective
- Neutral/unsure
- Somewhat ineffective
- Very ineffective

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q28 What obstacles do you foresee appearing when trying to implement these posters in the introductory chemistry labs you've taught?

- The classrom(s) I've taught in already have posters like this
- There's no room in the classroom(s) I've taught in for posters like this
- These posters will be difficult to create
- Other ____
- None

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory chemistry lab (CH1010, CH1020, or CH1030)

Q44 Overall, how likely would you be to support implementing these posters in the introductory chemistry labs you've taught?

- Very likely
- Somewhat likely
- Neutral/unsure
- Somewhat unlikely
- Very unlikely

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q37 How effective do you think these posters would be at reducing improperly placed student-generated waste in the introductory biology labs you've taught?

- Very effective
- Somewhat effective
- Neutral/unsure
- Somewhat ineffective
- Very ineffective

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q38 What obstacles do you foresee appearing when trying to implement these posters in the introductory biology labs you've taught?

- The classroom(s) I've taught in already have posters like this
- There's no room in the classroom(s) I've taught in for posters like this
- These posters will be difficult to create
- Other ____
- None

Display This Question:

If Please select which in-person lab courses you currently teach, or have taught in the past (either... = Any introductory biology lab (2000-level BB lab course)

Q43 Overall, how likely would you be to support implementing these posters in the introductory biology labs you've taught?

- Very likely
- Somewhat likely
- Neutral/unsure
- Somewhat unlikely
- Very unlikely

Q45 (Optional) Please write any other feedback you have about this solution.

____

End of Block: Proposed Solutions

Start of Block: Final Questions

Q41 (Optional) Please write any other solutions you think may help reduce student-generated lab waste in WPI's introductory chemistry and biology labs.

____

Q42 (Optional) Please write any other information you'd wish to share with our team.

____

Q43 (Optional) If you would be willing to be contacted by our team in the future to further discuss the reduction of student-generated lab waste at WPI, please provide your preferred email address.

____

Appendix G: Survey Distribution Procedures

Below outlines how we distributed our student survey (see Appendix E) and instructor & teaching assistant (TA) survey (see Appendix F).

Distribution of Student Survey

To distribute our student survey, we used emails, posters, and social media advertisements. Looking first at the emails, we identified every major at WPI that has introductory biology or chemistry courses as a graduation requirement (15 majors total). We then emailed the administrator of each of these majors requesting them to forward our survey to all students in those majors. Figure G1 shows the full email we sent to each administrator. All administrators except the one for computer science agreed to forward our survey.

To: Administrator of each relevant major

Subject: Distribution of IQP Survey about Introductory Chem and Bio Labs

Hello,

We are an IQP group that is conducting a survey to investigate the factors contributing to waste output in undergraduate lab courses at WPI. This survey is aimed at students who have taken or are currently taking introductory chemistry or biology labs.

We are hoping to send an email to all students majoring in [MAJOR(S)] with a request to take this survey, as this major requires its students take some introductory chemistry or biology labs. We pasted this email below. Would you be able to send this email to these students, or could you redirect us to someone who is able to do this?

Best Regards,
The Green Labs IQP Team

To: All students majoring in [MAJOR(S)]

Subject: ($25 Amazon Gift Card Raffle Entry) IQP Survey about Undergraduate Chem and Bio Labs

If you have either taken or are currently taking a chemistry or biology undergraduate lab course, your feedback would be greatly appreciated on this survey. Responses to this survey would assist in a better understanding of the factors contributing to the amount of waste produced from these labs and help to devise strategies to make labs more sustainable.

Participation in the survey is entirely voluntary and anonymous, and completion of the survey will provide entry into a raffle for a $25 Amazon gift card. This survey should take about 6 minutes to complete:
[SURVEY LINK]

Thank you for your time,
The Green Labs IQP Team

Figure G1: Email we sent to each relevant administrator to distribute our student survey. We replaced the bracketed fields with the relevant text before sending each email.

We also created and hung posters around the WPI campus advertising our survey. Figure G2 shows what these posters looked like. We specifically hung them around the walls of six academic buildings, the campus library, and the campus center. We hung up 25 posters total.

Additionally, we made posts on relevant social media platforms advertising our survey, and including a link in the posts for students to take it. These platforms included the WPI Discord server and Subreddit. Both are communities frequented by WPI students.

Figure G2: Poster advertising our student survey. The QR code at the bottom linked to the survey.

Distribution of Instructor & TA Survey

To distribute our instructor & TA survey, we first contacted the heads of WPI's Chemistry & Biochemistry department and Biology & Biotechnology department. We sent them each an email asking them to forward the survey to all professors and TAs who've taught the introductory chemistry or biology labs. Figure G3 shows these full emails.

The chemistry head responded quickly to us with a short email saying her department does "not wish to participate in [our] surveys at this time." The biology head never responded so we sent the same email to a biology professor we had contacted before. This professor forwarded the survey to 3 professors who teach the introductory biology courses, and she asked each to send the survey to any of their TAs.

We further distributed the survey during our lab observations this term. We printed a QR code to the survey and invited the professor and TA of each of the 2 CH1010 sections we observed to fill out the survey at some point after the lab. We made sure to inform them that the department head already denied sending the survey out.

To: [Biology OR chemistry department head]

Subject: IQP Green Labs Request to Distribute Instructor and TA Survey

Hello,

We hope this email finds you well. We are an IQP team working on ways to make WPI's teaching laboratories more sustainable. We aim to reduce the amount of waste these labs generate, primarily single-use plastics. We are conducting a survey to investigate the factors contributing to waste output in undergraduate lab courses at WPI. This survey is different from the recent student surveys, as this survey is focused on the perspective of Professors/Instructors and TAs who have taught BB 2000-level courses.

We would greatly appreciate it if you would share our message and survey to an alias with Teaching Assistants and Professors/Instructors who have taught BB 2000-level courses.

We appreciate you working with us. Thank you for your time and take care!

Best regards,

The Green Labs IQP Team

To: Instructors and TAs who have taught [BB-2000 level lab courses OR CH1010-CH1030 lab courses]

Subject: IQP Green Labs Instructor & TA Survey

With the help of your participation in this survey, the Green Labs IQP team intends to understand the contributing factors to the amount of waste produced from introductory teaching labs at Goddard Hall.

The survey is very brief and will take about 10 minutes to complete. Please click the link below to go to the survey website (or copy and paste the link into your Internet browser).

[SURVEY LINK]

Your participation in the survey is completely voluntary and all your responses will be kept confidential. No personally identifiable information will be associated with your responses to any reports of these data. The WPI Institutional Review Board has approved this survey. Should you have any comments or questions, please feel free to contact the Green Labs team at [EMAIL ADRESS]

Thank you very much for your time and cooperation. Feedback from you is very important to us.

Best regards,

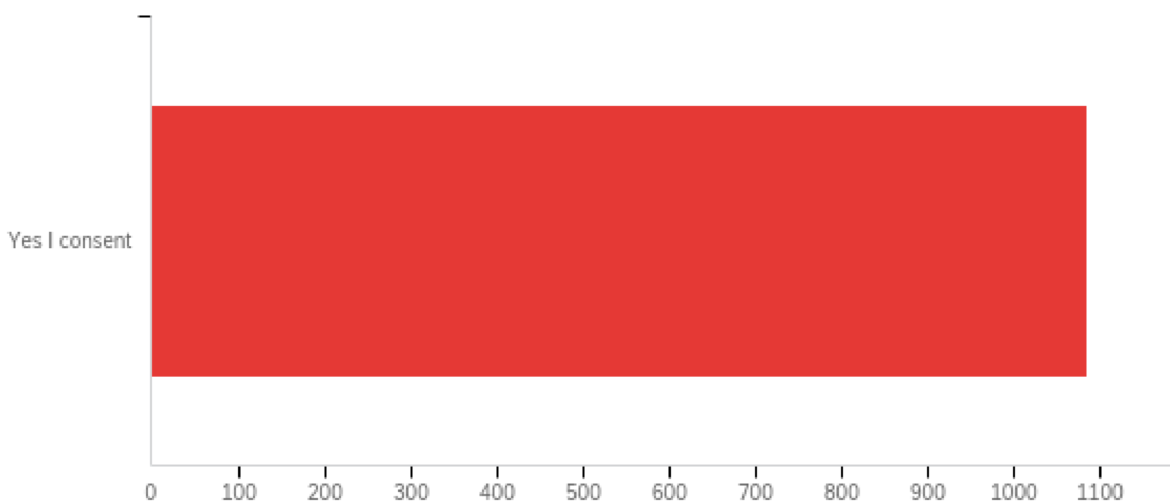
The Green Labs IQP Team

Figure G3: Email we sent to each relevant department head to distribute our instructor & TA survey. We replaced the bracketed fields with the relevant text before sending each email.

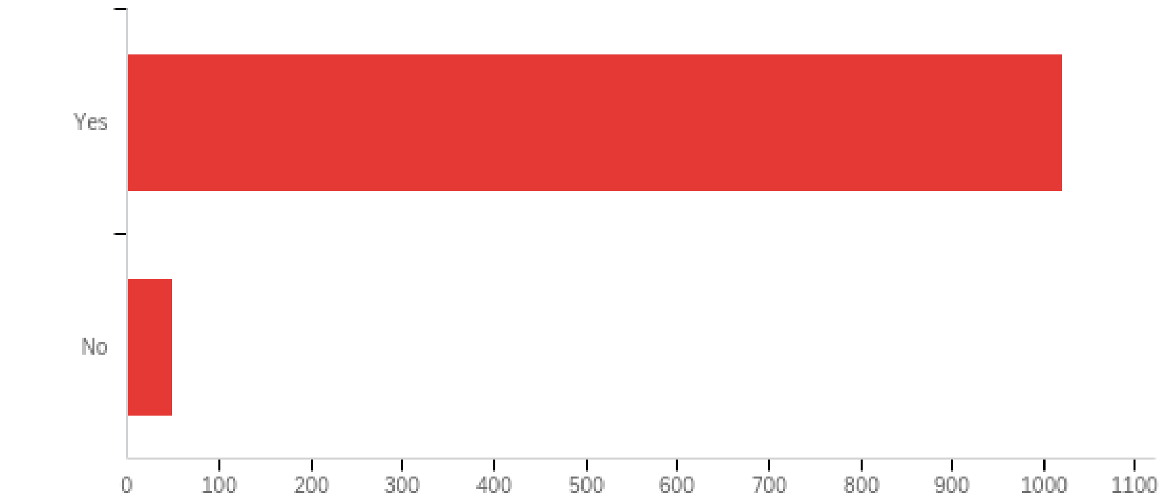
Appendix H: Raw Student Survey Data

Below shows the raw, data acquired from our student survey (see Appendix E). The data is broken down by each question asked. The data is entirely unfiltered, except for the optional write in questions. For these questions, we received well over 50 responses on each question just saying "n/a" or something similar. We have omitted these responses from the data for the sake of brevity.

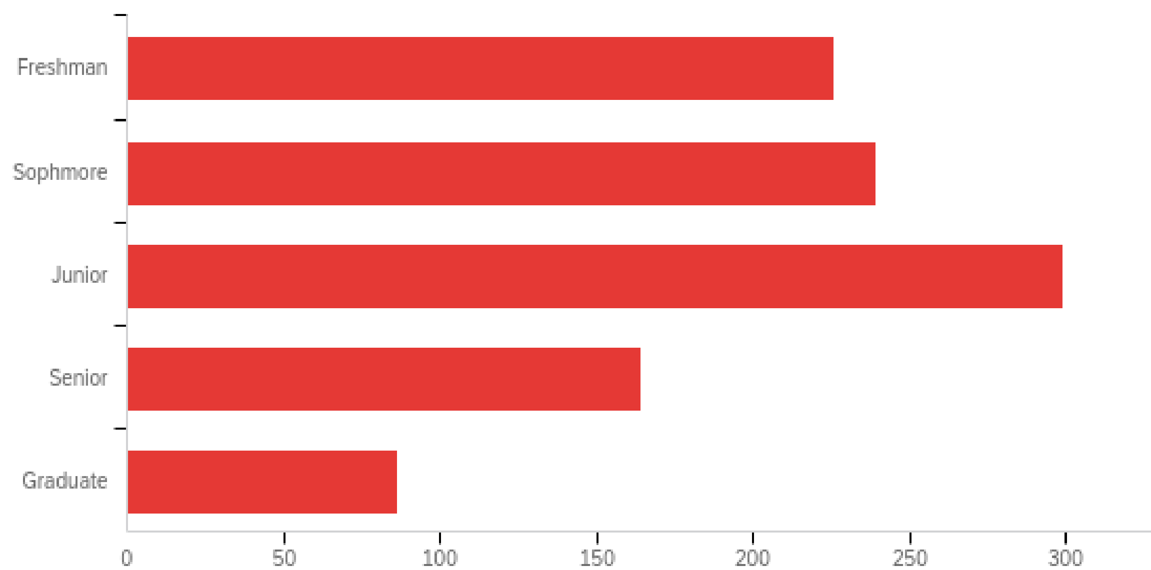
Q1 - Our team is conducting this survey for an IQP project focused on reducing the amount of student-generated waste in WPI's introductory chemistry and biology lab courses. Your responses will help give us a better understanding of the waste in these courses, and give us valuable feedback on our proposed solutions. The intended audience for this survey is students who have taken in-person introductory biology or chemistry labs at WPI. At the end of the survey is a link to enter into a raffle for a $25 Amazon giftcard. Your responses are anonymous and will be used as data in our IQP report. Please select the option below if you consent to this.



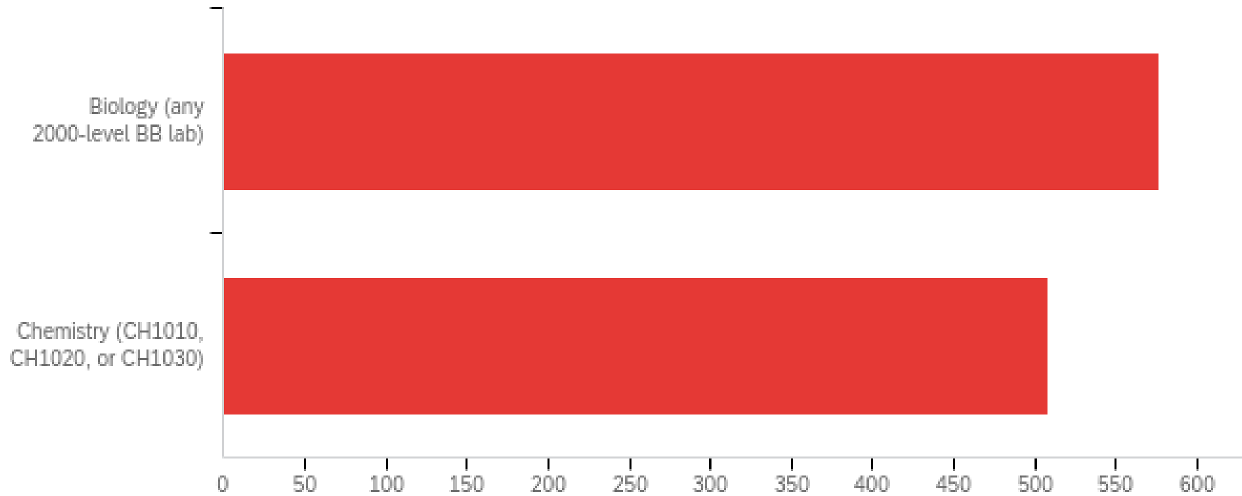
Q3 - Have you taken an in-person introductory biology and/or chemistry lab at WPI? These labs include CH1010, CH1020, CH1030, and all 2000-level BB labs.



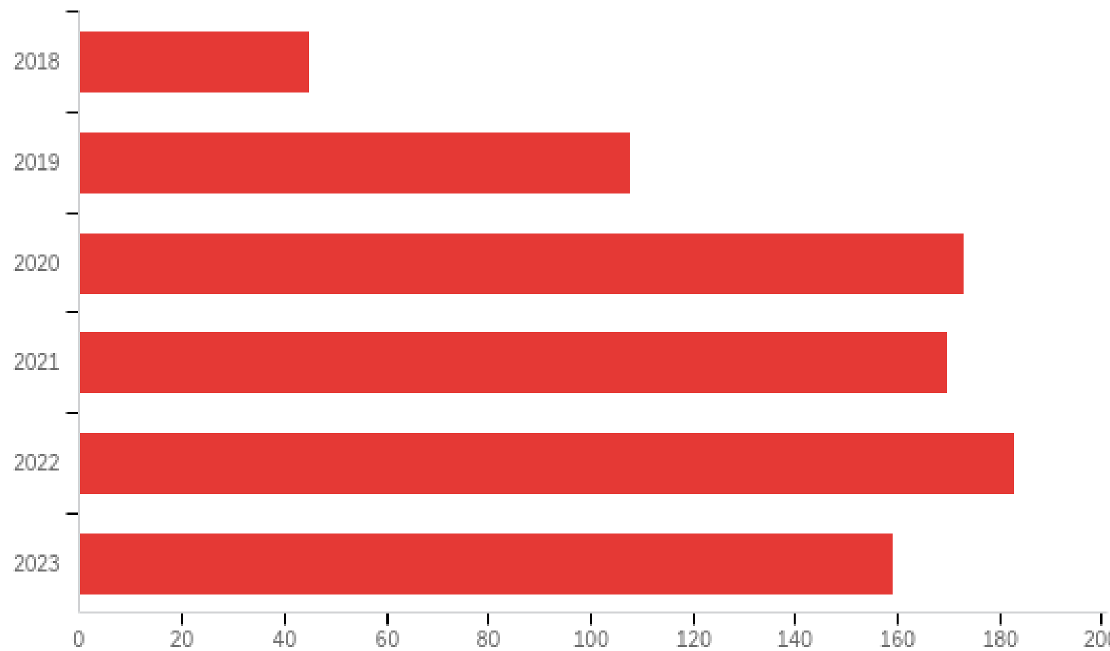
Q3 - What grade level best describes you?



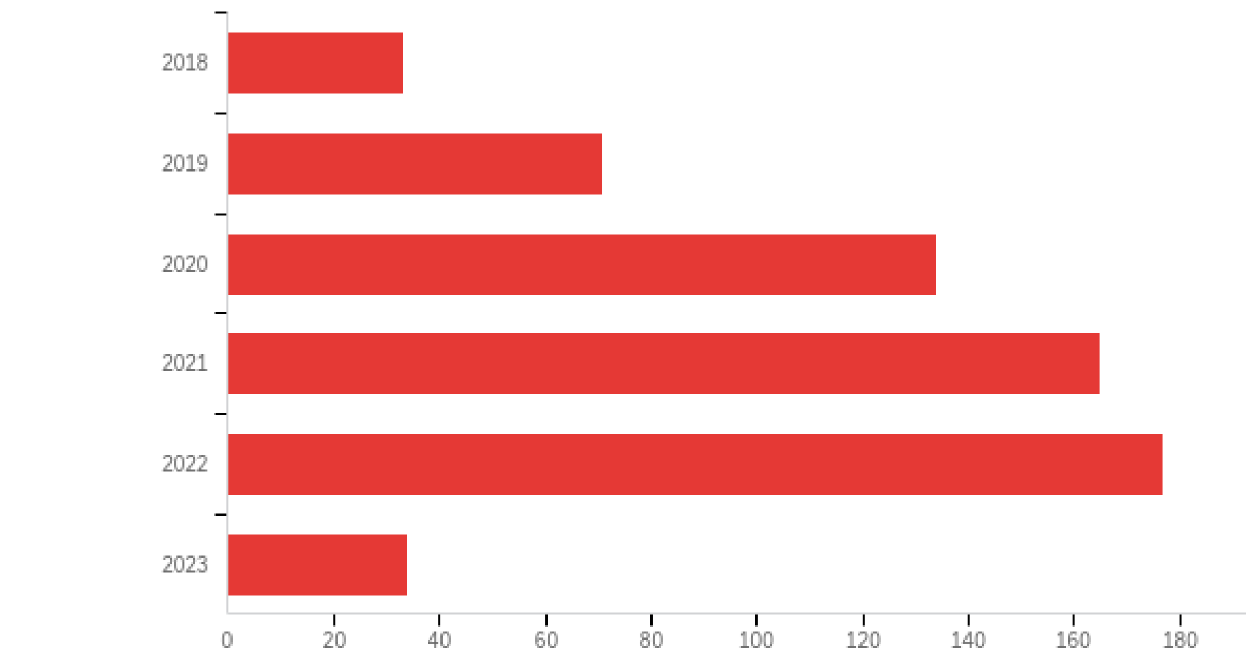
Q39 - What in-person, introductory labs have you taken at WPI?



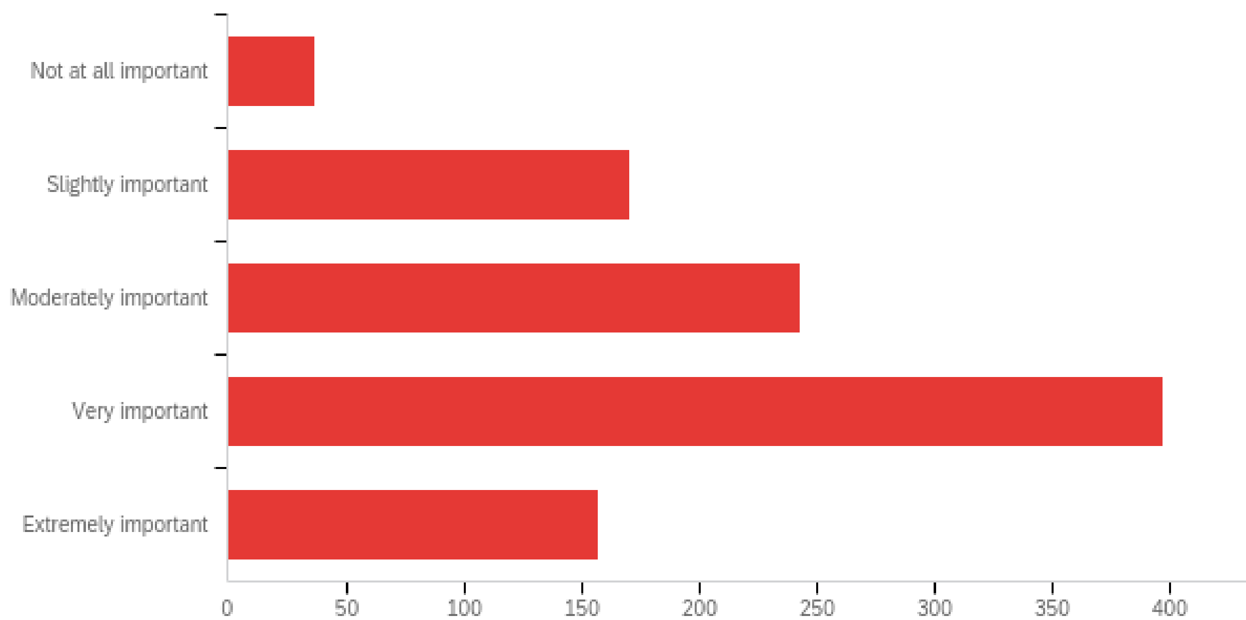
Q41 - What years did you take those introductory biology labs?



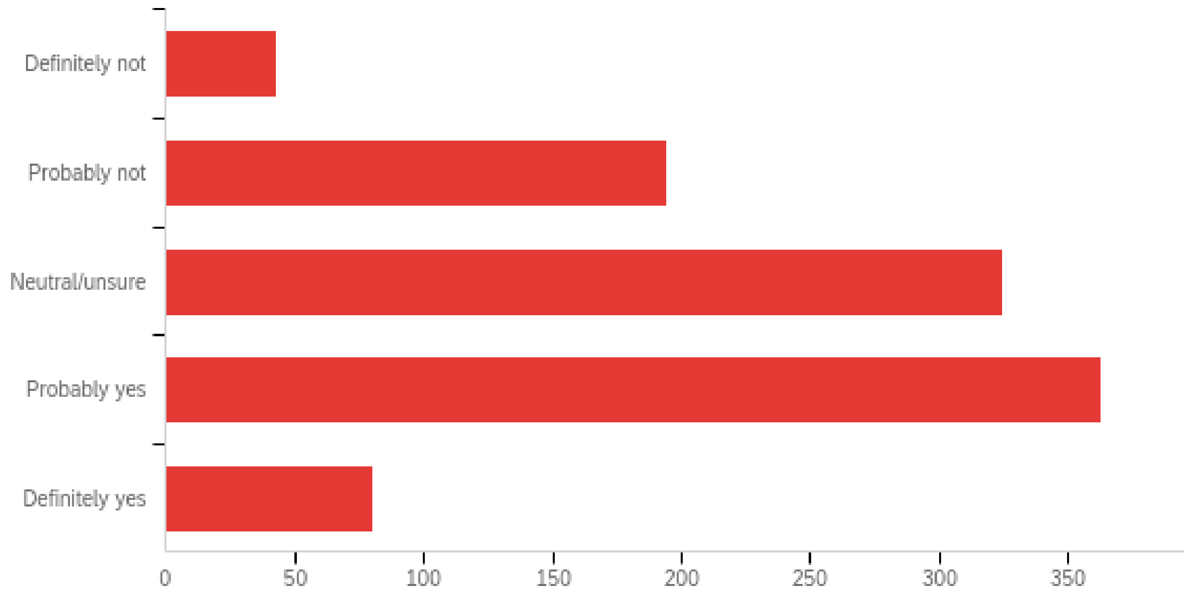
Q45 - What years did you take those introductory chemistry labs?



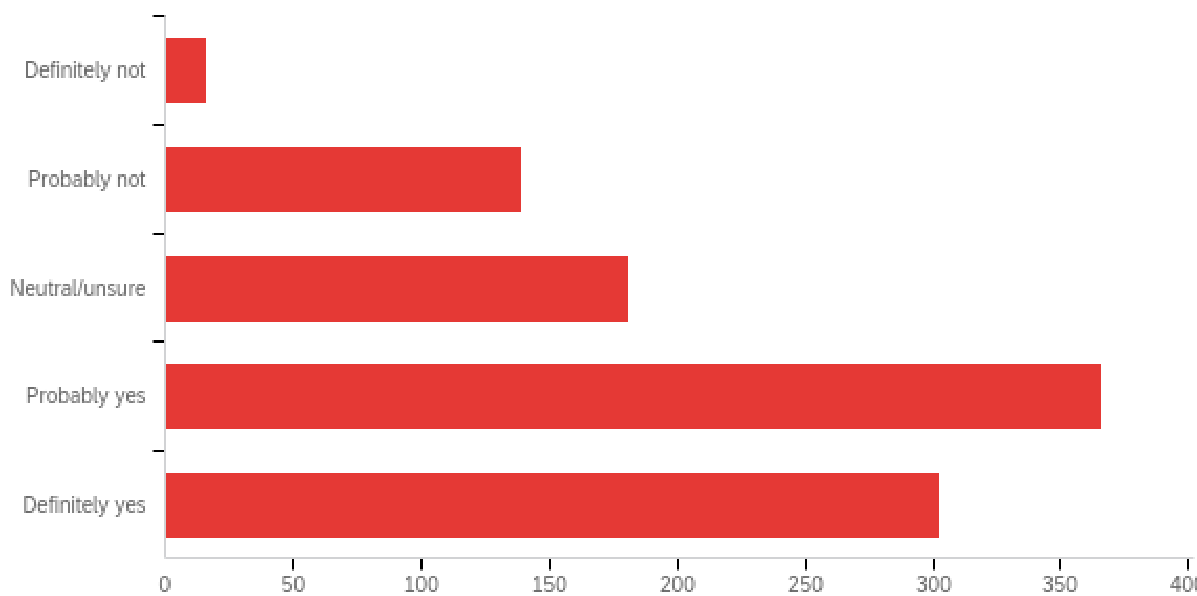
Q15 - How important of an issue do you think reducing lab waste is?



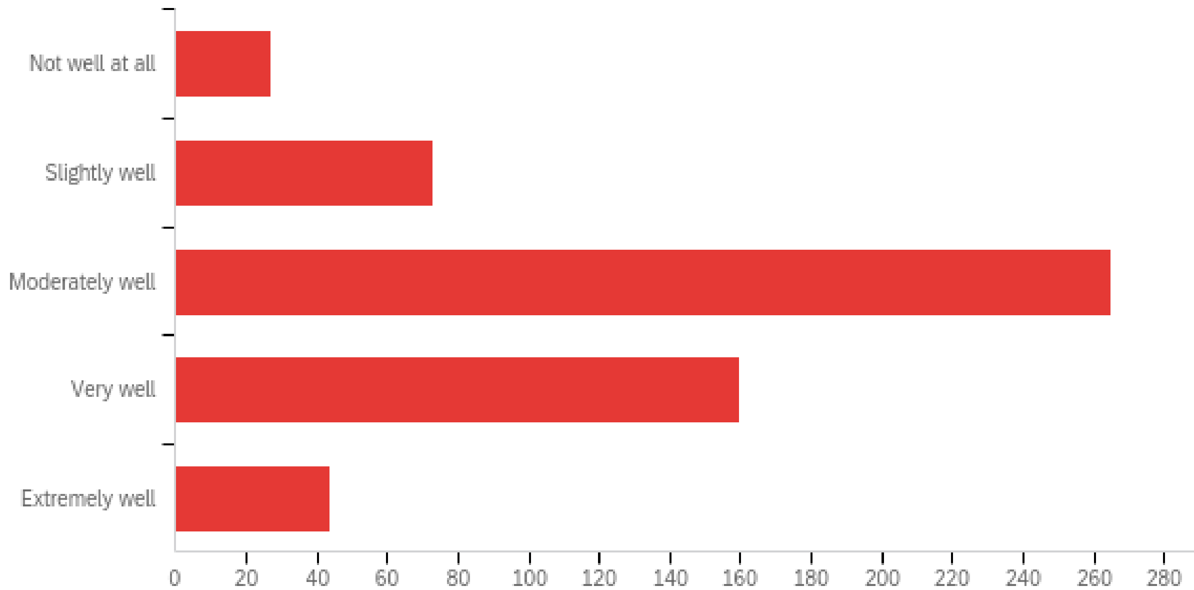
Q37 - Do you think WPI has sustainable, environmentally friendly practices in their introductory biology and chemistry labs?



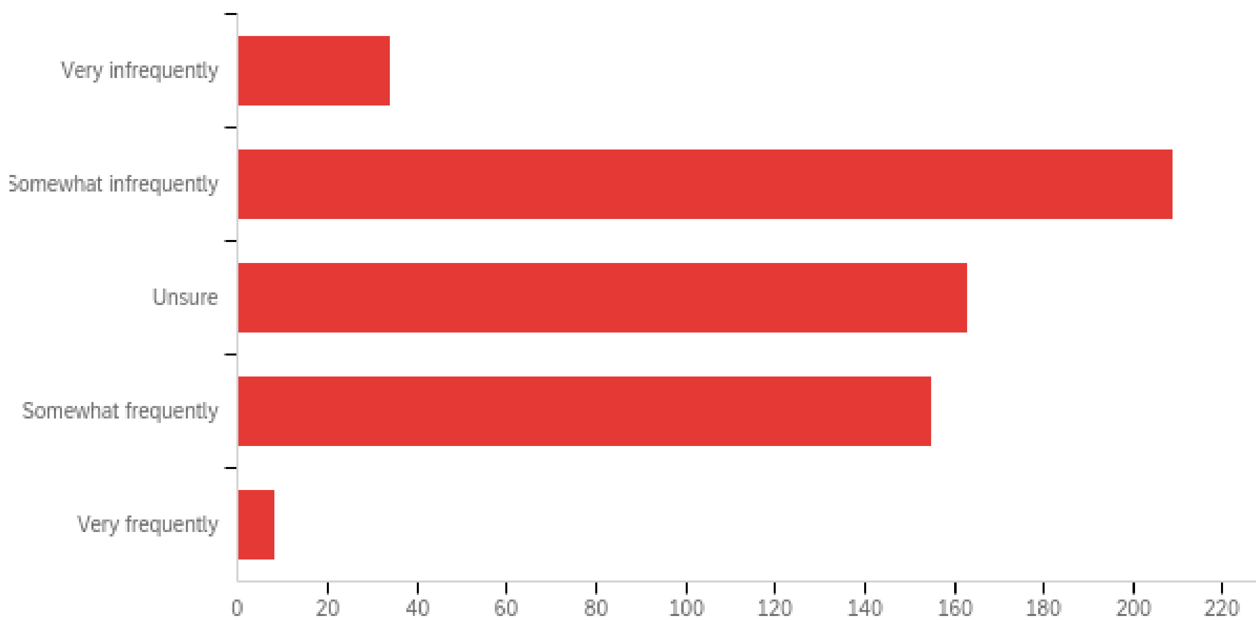
Q38 - Do you want WPI to have more sustainable and environmentally friendly practices in these labs?



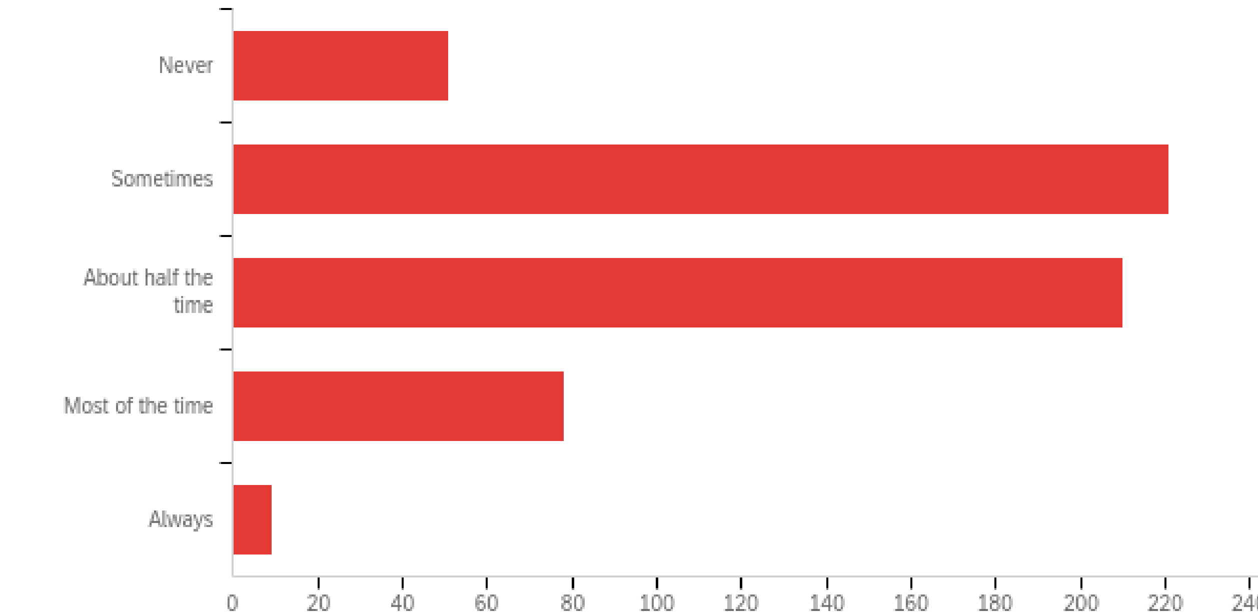
Q4 - When performing experiments in the introductory biology labs you've taken, how well did you usually understand the procedure?



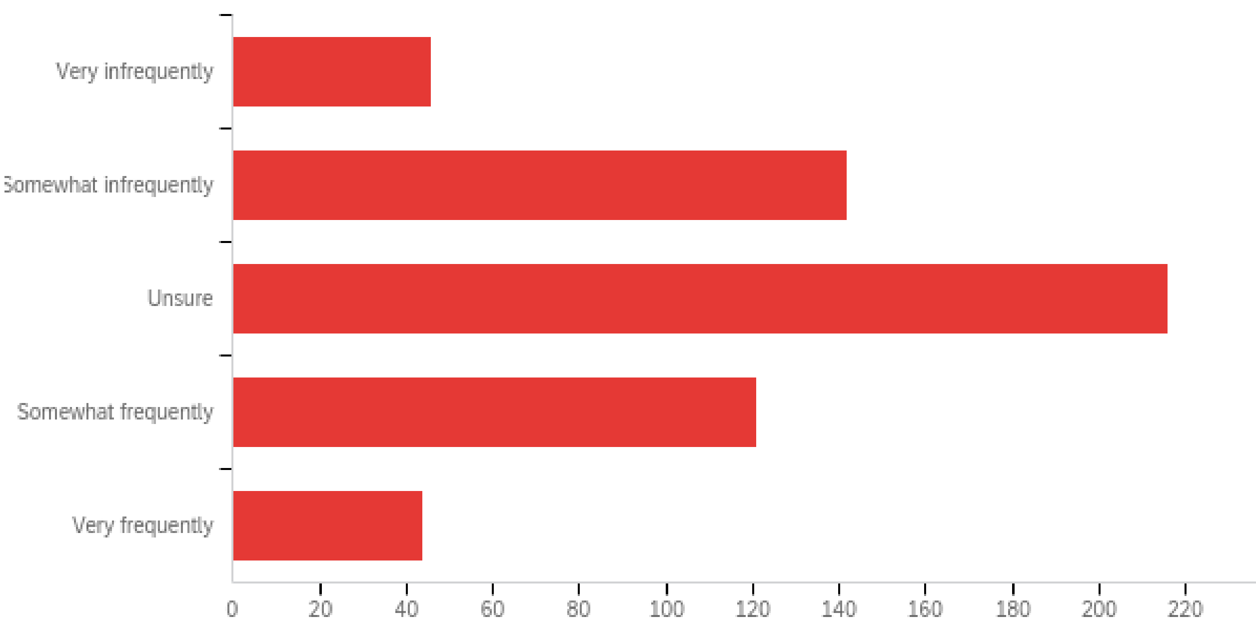
Q5 - How often did you make experimental errors in the introductory biology labs you've taken?



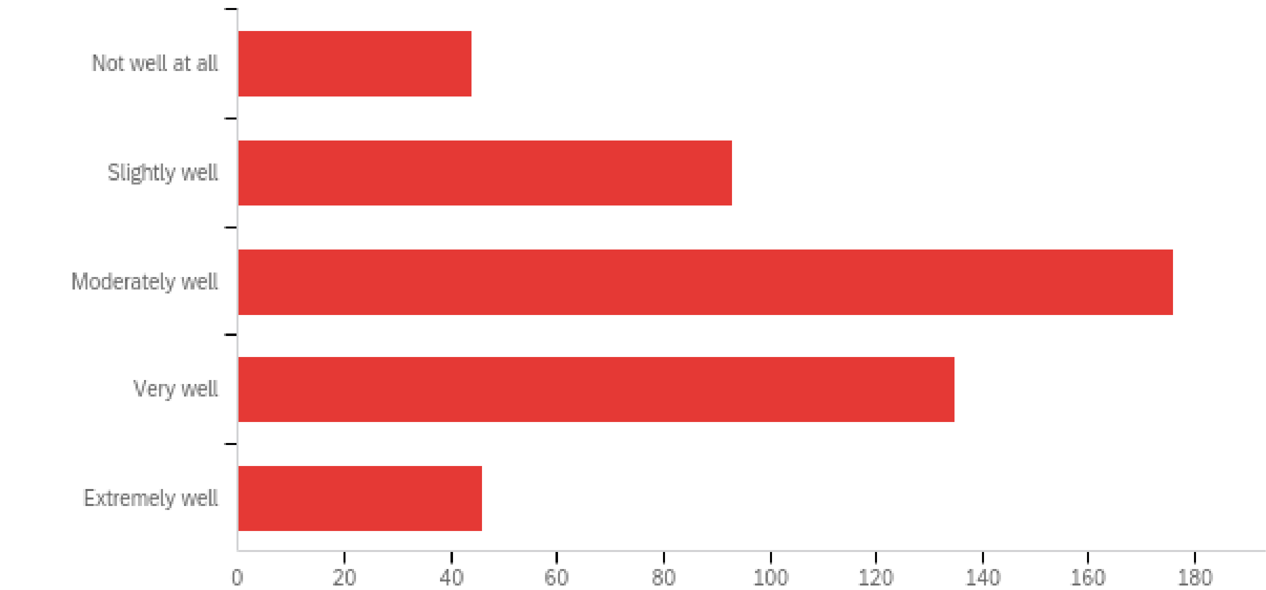
Q6 - In the introductory biology labs you've taken, how often did you need to redo experiments for preventable reasons?



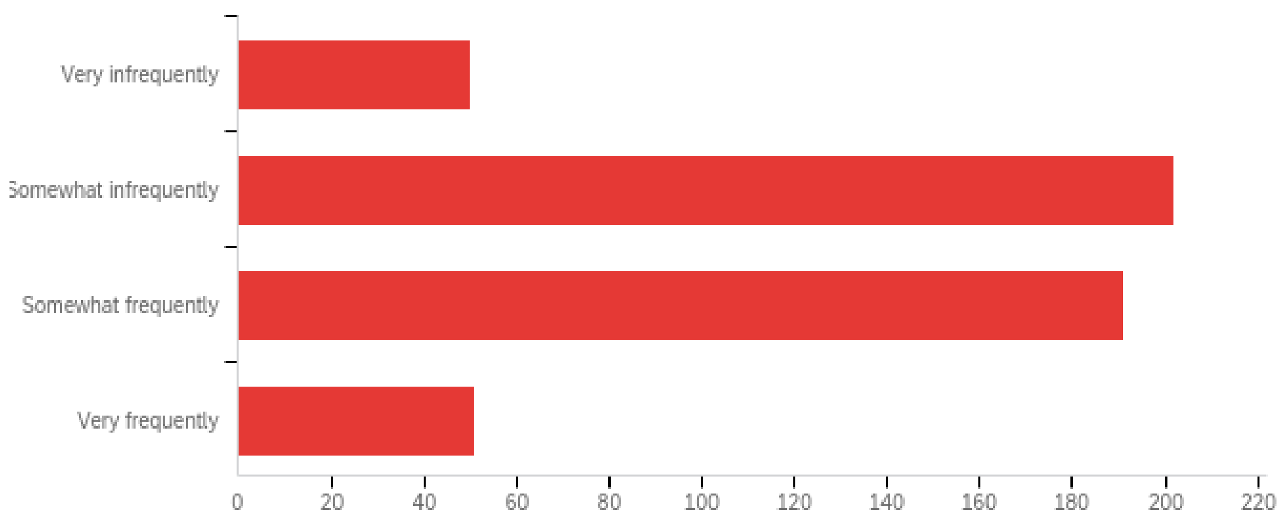
Q51 - In the introductory biology labs you've taken, how often were you confused on where to put your waste?



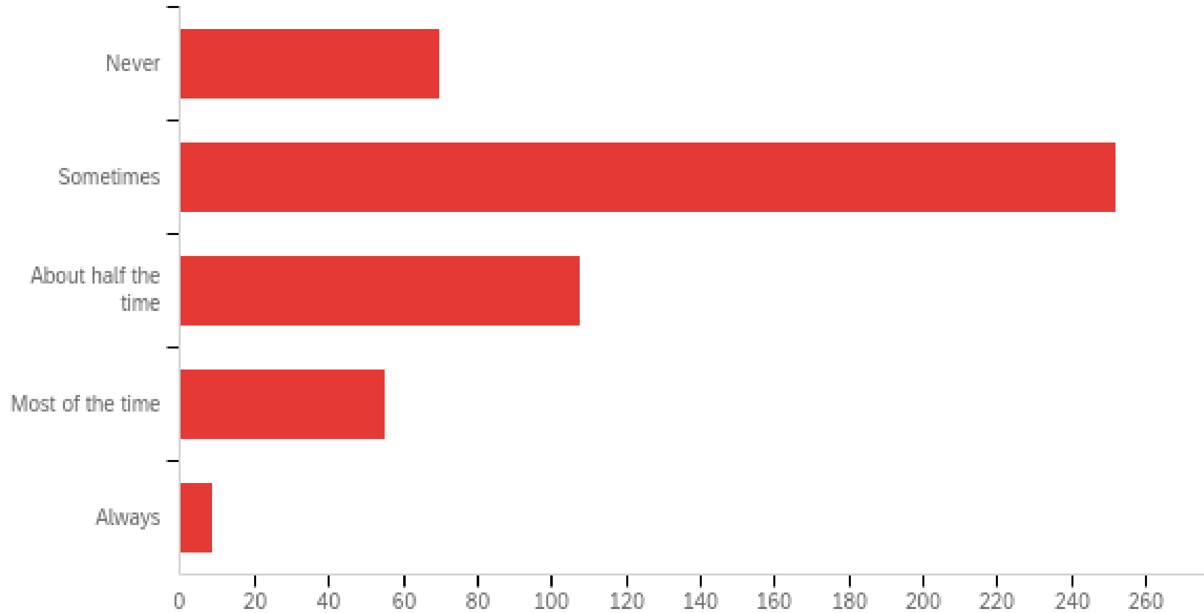
Q48 - When performing experiments in the introductory chemistry labs you've taken, how well did you usually understand the procedure?



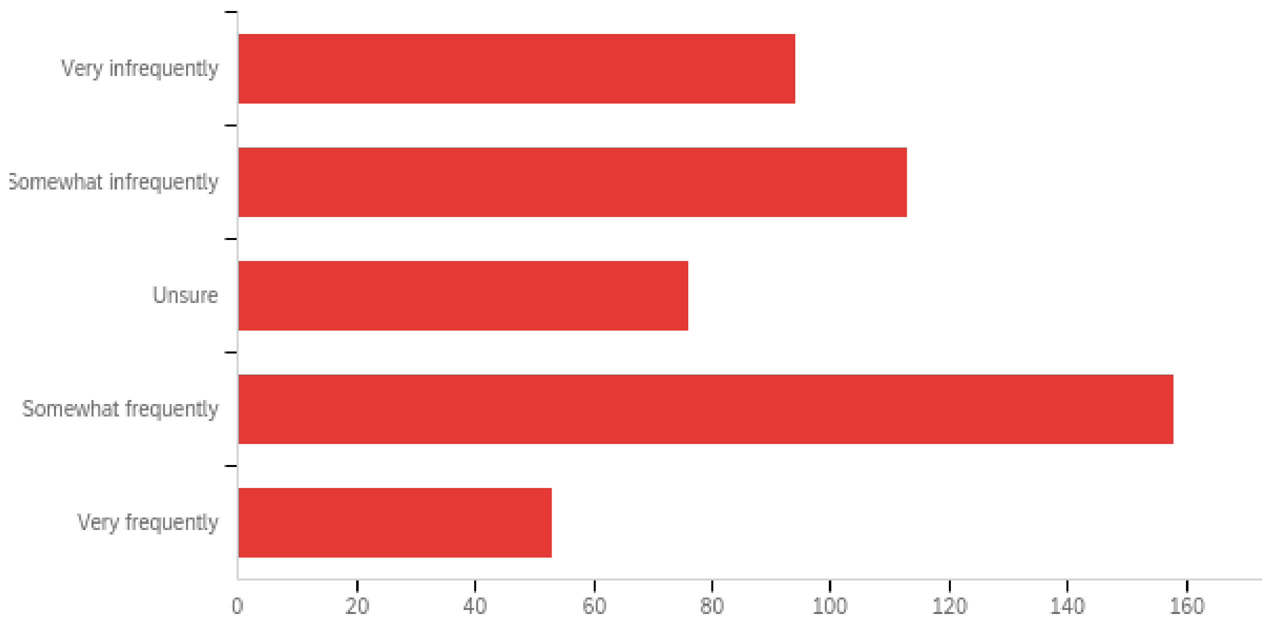
Q49 - How often did you make experimental errors in the introductory chemistry labs you've taken?



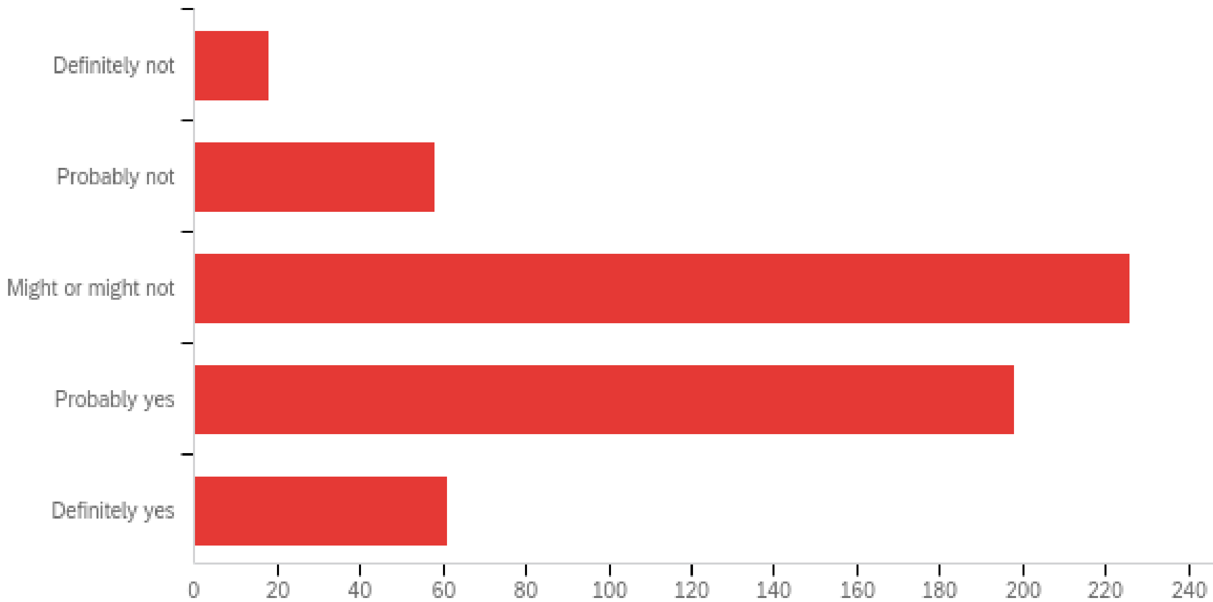
Q50 - In the introductory chemistry labs you've taken, how often did you need to redo experiments for preventable reasons?



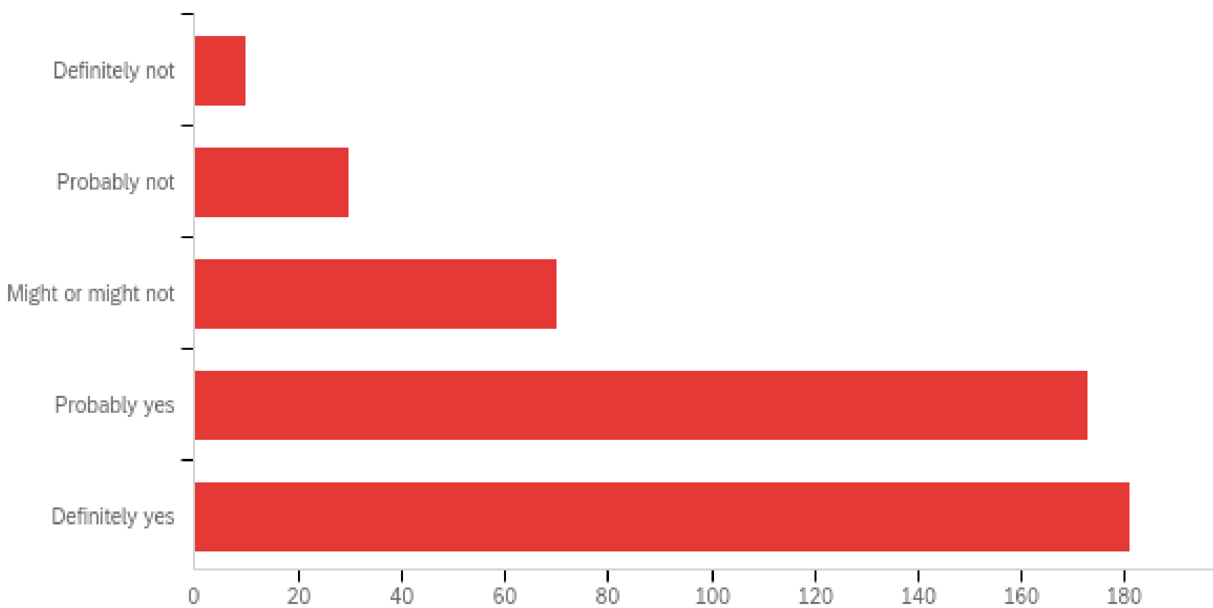
Q52 - In the introductory chemistry labs you've taken, how often were you confused on where to put your waste?



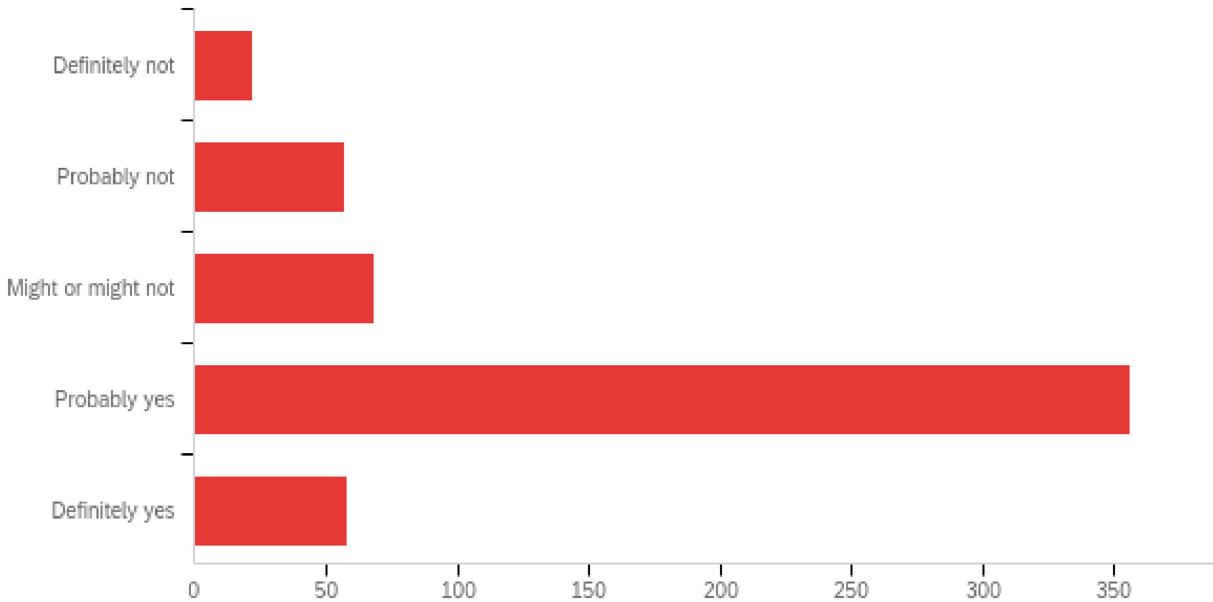
Q18 - Would you like if this idea was implemented for the introductory biology labs you've taken?



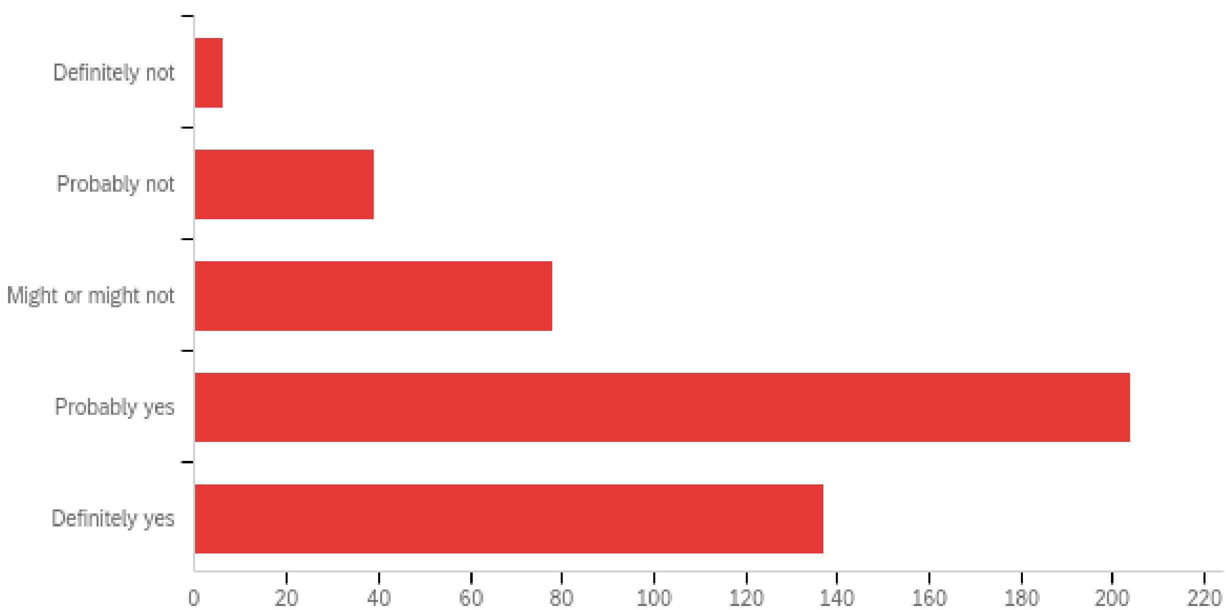
Q53 - Would you like if this idea was implemented for the introductory chemistry labs you've taken?



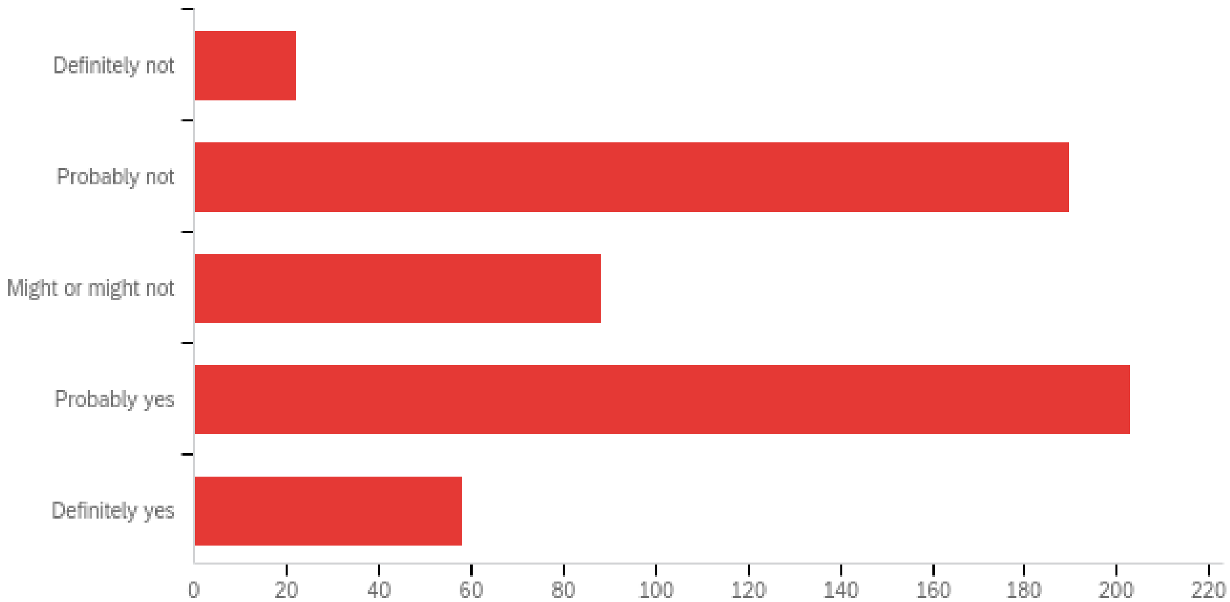
Q20 - If this idea was implemented in the introductory biology labs you've taken, would it have helped you make less errors in your experiments?



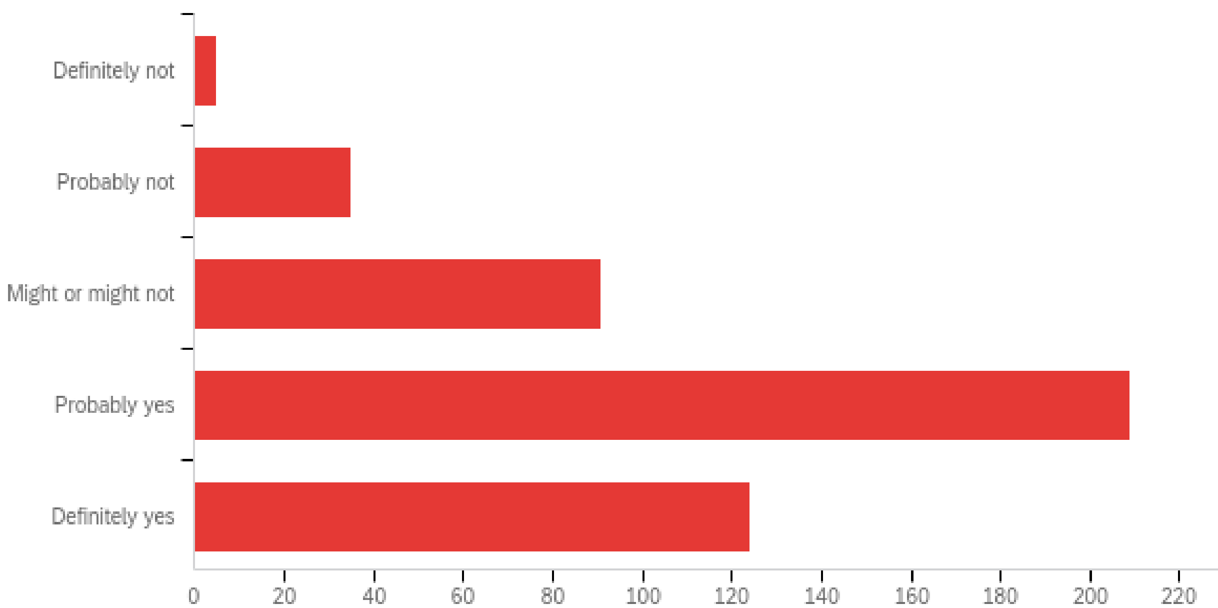
Q54 - If this idea was implemented in the introductory chemistry labs you've taken, would it have helped you make less errors in your experiments?



Q21 - If this idea was implemented in the introductory biology labs you've taken, would it have reduced how often you needed to redo experiments for avoidable reasons?



Q55 - If this idea was implemented in the introductory chemistry labs you've taken, would it have reduced how often you needed to redo experiments for avoidable reasons?



Q22 - (Optional) If you have additional thoughts on this idea, please write them here.

For me, for chem was where the biggest waste was at. Because we have to make our own procedures, it is more likely to make mistakes. And we are supposed to make mistakes in lab to learn, the problem are the amount of mistakes that contribute to lab waste.

Couldn't play the video but I like the idea!

With techniques the lab instructor / TA believed we would not know, they demonstrated in lab or gave diagrams in the discussion - perhaps this could happen more frequently? This may make grading different moving forward, but if they were checked by a professor before being allowed to proceed (such as with the projects) it may help some!
I think mistakes are a natural part of learning a new skill like lab work, and while videos explaining procedures might reduce a sml amount of waste, they may take away from the experience of figuring out the experimental setup and procedures on your own.
I think it's difficult sometimes to generalize about "waste" being a bad thing during a repeat experiment. In biology and chemistry the largest part of the scientific method is the repeating of experiments to ensure that the procedure can be modified to yield different results. Waste is often a byproduct of the experiment. I think that waste considered should also include gloves, Serological pipettes, plastic pipettes tips, plates (the two soil bio labs go through 100s each week). Also, consider reaching out to the bio/Chem dept admins to get this survey distributed!
In one of my lab classes we were given these videos sometimes or we looked for them ourselves in other classes.
For experiments where materials can be reused for redos, I think making mistakes would be the best way to learn to do it right. This differs depending on the materials and chemicals involved.
I think this is a great idea for introductory-level classes where not all students have lab experience under their belt. It could be a way to build confidence in the lab and reduce accidents or errors.
I don't know why this isn't done more often. It would significantly reduce the amount of time a lab takes. And it would have allowed us to focus more on lecture. A simple, quick, efficient, right to the point video is way better than a confusing lab lecturer
Usually professors show how to do proper lab techniques in person before the lab. So I don't know how much this would change anything
nice good
Using scales and balances are an important skill to use
I think that the waste disposal should absolutely be part of the procedure given to students (its not really giving any answers away)
Most professors already give you basically the full procedure on lab day anyways, so this is a good way to implement it.
Some of the bio labs have example videos of the professor teaching the course online through COVID, and the videos are posted on canvas, but I'm not sure how helpful those were really
I just don't think I would actually watch the video. Also, mistakes happen
Most did have such introductory videos, to varying degrees.
For introductory chemistry this sounds like a great idea. For 2000s bio labs this is a little redundant, as I generally recall profs covering most setup things in lab. It would be a nice teaching tool, maybe. Additionally however, I wouldn't say the majority of avoidable waste comes from redoing a mistaken experiment, but from concerns about sterility where applicable. In the case of the latter, personally I'd say it's more important to preserve the integrity of the experiment when setting it up than to realize it got messed up after the fact (i.e. it doesn't work bc of contamination or something) and have to redo it entirely. Finally

something I value about the introductory sequence bio labs is the open and healthy attitude they foster towards failure and learning from mistakes. Focusing on avoiding waste from procedural repeats is fine, but not at the expense of an attitude that discourages the natural errors that occur when trying something for the first time to the point that a student might be hesitant to try something for fear of waste. I might be overblowing it though.

The method is not feasible and does not apply to my academic research

Minimize waste in the experiment

This is recommended and I agree with it

The method is not feasible and does not apply to my academic research

Reduce waste in experiments

This really depends on the professor but also makes mistakes is part of the learning process.

I think making errors in labs is a crucial part of the learning experience. If preventable errors in labs contributes significantly to waste AND the waste produced by these labs is substantial, then I think a more general approach downstream to reducing waste such as treatment would be a better approach. Understandably, this isn't easy with a waste container with mixed/unknown contents. Also, this gives much more information on how to do the labs at least than when I took the class in 19/20. We had only an objective and had to fully write a procedure from scratch. Showing the lab done would skip this cycle of prewriting for the lab.

Most of the time the Professors or the TAs/PLAs poured our liquids for experiments, so if they poured too much then it was not really our fault.

Although I would have loved this idea and watched the videos, many people wouldn't have necessarily taken the time to watch them. With that said, if there is only one video per experiment and it is less than 5 minutes long, I would say most people would watch.

My instructor showed us how to do the procedure in the beginning of class, so I think having to watch the video before class and remember every step would be harder than watching it during class. I'd probably not want to spend that time and be expected to remember the procedure for so long before doing it

i think this is a good idea, however i foresee a lot of students either not watching the videos or, if they’re required, putting them on in the background and not listening. this could become a problem if lab instructors start to rely too heavily on the videos

The point of chem lab is to mess up and learn how to find the procedure that is needed for the experiment and how to gather data from trial and error. They show and tell you how to do things in the lab but messing up is part of the process on learning how to get the correct data and make sure the data analysis is correct. I think it's a good way to reduce waste but it almost defeats the point of the lab. This might be helpful in more advanced labs than the introduction labs because the introduction labs are used for trial and error but the more advanced labs are where more expensive things are used.

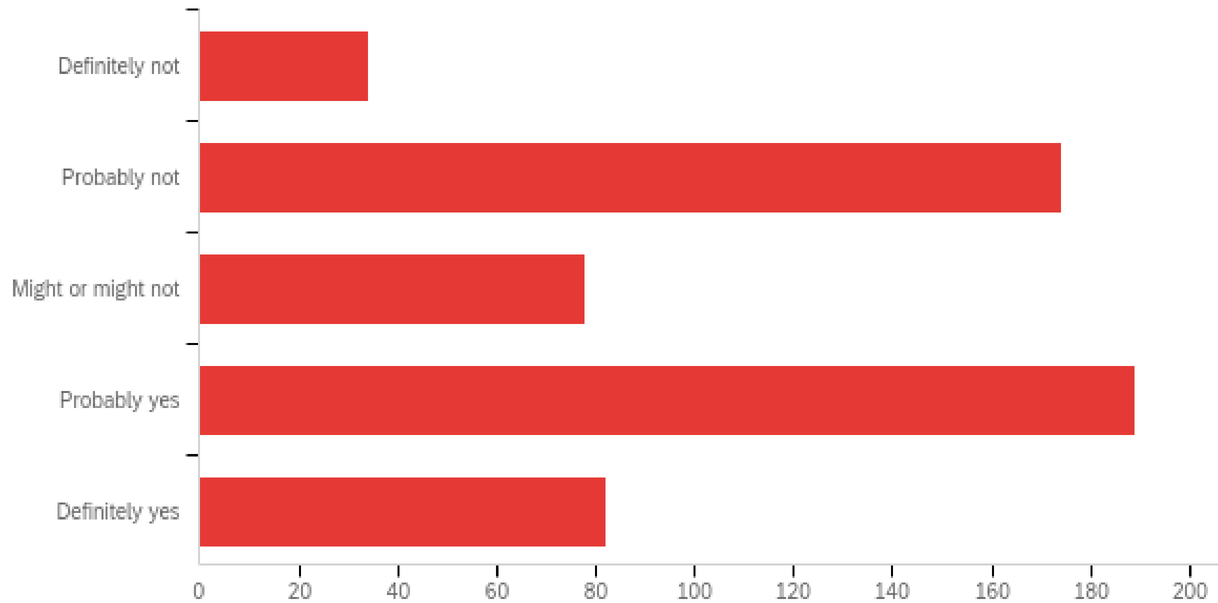
I think it is a good idea

I like the idea of the videos, I’ve had them for all my Chem labs but I think it could be more beneficial to and in person demo. Sometimes the videos had to be watched much earlier than the day of the actual lab, and I would have forgotten some of the steps taken by then.

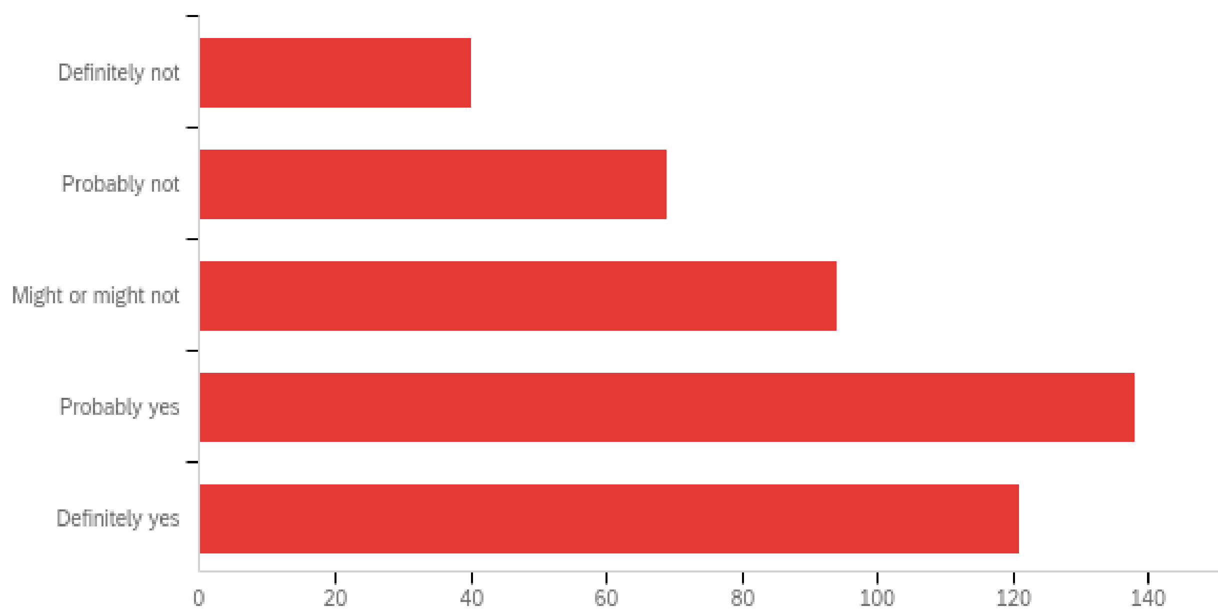
I think making mistakes is a very important part in learning, so I don't think that is something that should be avoided
I understand reasons professors would not particularly like this method because there is a fair amount of figuring it out on your own that comes with this. As long as there was explicit instruction on where to dispose what waste, I think this will help tremendously.
At one point, close to the end of the course, we had to do a very long experimental procedure with little direction. My group had to redo the experiment 4 times, and wasted many chemicals and of course time. This would help tremendously.
I think that having more TA and PLA assistance during time in lab is the best way to reduce errors. For one of the 3000-level BME labs I have taken, there were 3 TAs and 1 professor present, and it was one of the smoothest running procedures I have ever completed.
Maybe add a section to the video along the lines of "common mistakes"
I think it is challenging because making mistakes is a great learning opportunity. I could see people not taking the prelabs as seriously. Also, so cell culture labs, you need to produce a lot of waste to prevent contamination.
There just a lot of error in the introductory labs that don’t necessarily come from set up
Love this! This would also make me feel more confident when walking into lab, so hopefully I would make fewer mistakes and spend less time in the lab
I like this idea. It would also be a time saver for set up so more time could be allocated towards other questions that may be encountered further down the procedure.
I think if this were to be the case it would have to be the shortest most straight forward video in the entire course. Theres already enough information being thrown at the chem students
if theres videos, keep them short or people will get very bored
I love this idea and I think it’ll make chemistry much more approachable a WPI!
I like the idea but I feel like pictures of the setup and little notes might be more beneficial because it still helps without giving as much away
Here is to share with you the lab might use to save money tips: youdaoplaceholder9 system halved: Homologous recombinant link vectors can be system halved
Especially at the introductory level, the mistakes are a huge part of learning. Nobody cares about the data we gather. No matter how silly or physically impossible our results end up, the grade is good if we learned how to use the equipment. Sure, it took four tries to titrate what we were supposed to, but in the future, when it actually matters, it won't, because we spent time screwing it up and learning at the introductory level. No video can ever replace the embarrassment which ensures I'll never make the same mistake twice. It may help in the short term, reducing mistakes in that particular course, but the mistakes will still happen, just later, perhaps in a different class, or in a workplace, because true learning won't take place until the mistake occurs.
I think this does an effective job at preserving the nature of chemistry labs in that you/your group would still need to figure out the pre-lab independently. However, students may start to view the pre-lab as more of obstacle they have to overcome in order to unlock the videos. I think if the videos were made available for everybody at the same time (maybe the night before or the morning of the lab) as opposed to being made available when the student

completed the pre-lab, it could help to mitigate those feelings. Overall, this could definitely be useful, especially for students that did not take advanced chemistry in high school.

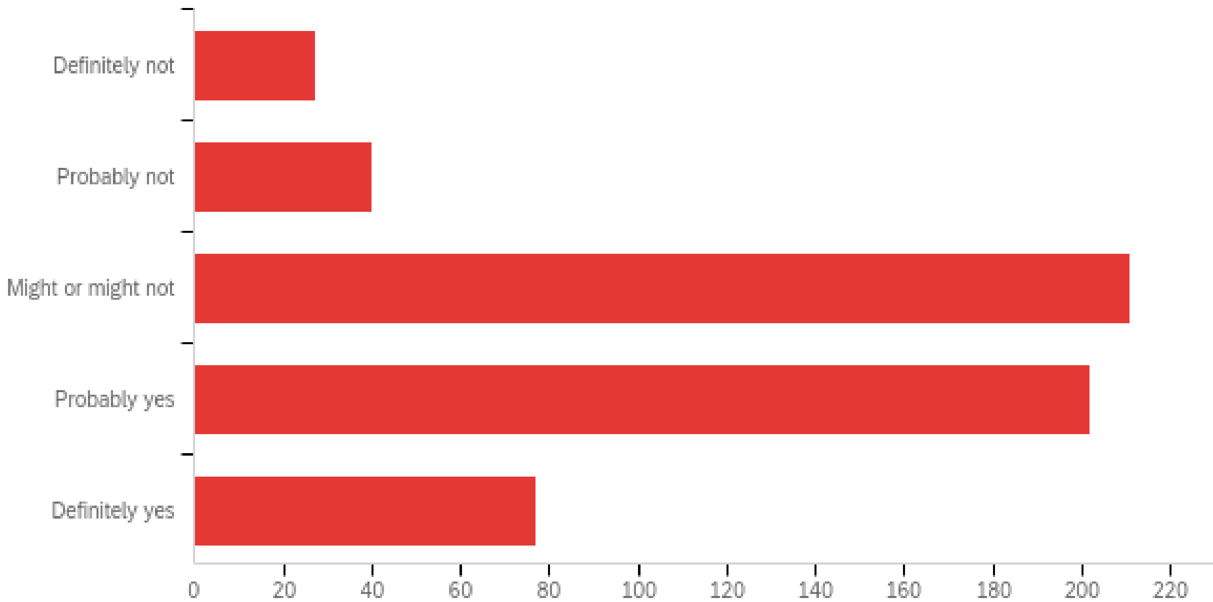
Q29 - Would you like if this idea was implemented in the introductory biology labs you've taken?



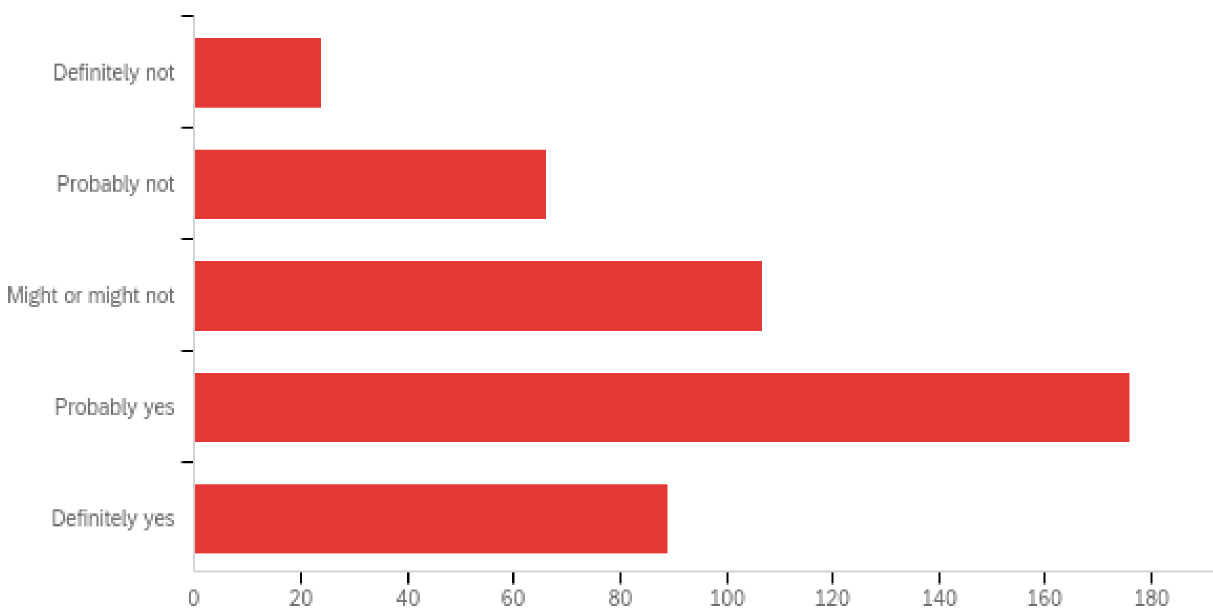
Q56 - Would you like if this idea was implemented in the introductory chemistry labs you've taken?



Q30 - If this idea was implemented in the introductory biology labs you've taken, would it have helped you reduce your waste output?



Q57 - If this idea was implemented in the introductory chemistry labs you've taken, would it have helped you reduce your waste output?



Q32 - (Optional) If you have additional thoughts on this idea, please write them here.

In a later Chem course this idea happened with an expensive chemical. If we needed more than our allotment of it we lost points. Not a bad idea, I bet it helped reduce waste. Wish it could have applied to more stuff though.

I think it might be unrelated to the want/need to reduce waste for positive reasons. Students should be educated in the waste process and what happens to their waste once they dispose of it. That way students want to reduce waste for environmental benefits rather than personal gain which would carry on into other areas of their life where waste disposal is a concern.

This puts lots of pressure on students who are often new to the subject and trying to learn, which could be counterproductive- showing them they can't make mistakes. Also, the amounts of certain reagents are already restricted, which could cause everyone to meet the threshold or be efficient.

would distract students from learning the experiment

Monetizing success will only hurt those who don't understand what they're doing or for whom things just don't work, for unknown reasons - like happened to me several times

This may be encouraging people to rush. Again, a large part of science is in the art of going back to the drawing board and trying something different. If there were incentives to be the first finished and use the least amount of products in the lab, you might lose that huge part of the scientific process. WPI also encourages trying new things and failing. These ideas might stray away from WPIs philosophy.

This'd only work on students who are careless and who'd be persuaded to give effort by a small reward. I don't think there are many careless students and I don't think the ones who are careless would be persuaded.

Again, this depends on the materials and chemicals involved with in the experiment. For some reason experiments, materials could simply be washed out and reused in the case of a redo. Making mistakes in this case I feel is essential to getting better results.

creating a threshold means that you would have to keep track of the amount of each device, chemical, and instrument that you used. This would then translate to more work for the professor and TA as well due to their authority over who would receive the incentive

this may help but to be honest, most students are more concerned with completing their work and getting a good grade then getting some gift card. Doing well in the class is worth way more than a $25 gift card.

This may effect the quality of the experiments as now the goal may be to use less and not to actually succeed in the experiment

It doesn't really seem like a good idea to incentivize creating less waste with money/gift cards. For example, if a class really wants to get the incentive, you could start to see more dangerous practices for the sake of reducing waste (such as, not switching gloves when you need to)

Providing ways of how waste could be reduced

This seems unwise, it would incentivise students to use less materials than directed

Often, we were given the amount of material we were starting with, and the goal was just to figure out the procedure. I don't think having the limit below that would be less wasteful, as the students are likely to make mistakes in the conversion to smaller volumes, which could throw off the ratios, leading to more waste at the end. Also, many reactions are tuned to specific volumes that the students may not understand.

Introuducing a waste incentive feels overengineered and may encourage students to prioritize reducing waste over performing the lab correctly.

I think rewards like this are an unhealthy incentive in the learning environment, that will lead to conflict within and amount lab groups, and make the classroom less of a socially-safe space for mistakes.

I would rather not turn in bad result data in favor of getting rewards. It is important to be able to freely do trials and errors and having lots of data.
If you think of wasted money as a bonus then I think everyone will save
It's important to reduce waste
Not a huge fan of collective punishment/rewards
I think the group waste threshold would cause some people, if they mess up, to feel like they ruined the chance at incentive. The intro labs were difficult enough for some people coming in with no experience and I think the fear of messing up would not help the situation. The idea of rewarding specific individuals for using less waste caters to people that might already have experience or know exactly how to do the experiment (maybe they have old lab reports, or have done the labs in high school if their school had a good program). These are introductory classes you should be able to make mistakes learning for the first time without feeling like you’re falling behind in that process if you’re not getting incentives. How would you keep track of the waste used? How would you make sure people are staying honest about materials used? And who would that burden fall on? If the TA/professor are focusing on make sure the people in the intro classes are not doing something dangerous in the lab as they run experiments, would they also be tasked with this/would they be willing?
This creates unfair incentives and punishes students who make a mistake, or whom have an experiment that doesn’t pan out.
Would definitely make me use less materials, I would probably feel like I'm being treated like a child however.
Good advice to promote the efficiency of doing research and all aspects
We don't need this approach for our academic research
The method is not feasible and does not apply to my academic research
Good advice to promote the efficiency of doing research and all aspects
It is good that the waste in the experiment is disposed of properly
This would make me fake more data, so I don't redo the experiment. Items are not waisted on purpose.
Again, this incentivizes doing the labs incorrectly instead of learning how to do them. Many students already fabricate data in these labs, and this would surely make that problem even worse.
I think this would make more pressure on not making a mistake rather than giving incentive to reduce net waste output.
If there was a competition between the class to see who produced the least amount of waste at the end of the lab, and maybe that group was given additional points on the lab or their final grade.
This might cause unnecessary tension between a group or between a class section. These labs are to learn and make mistakes, so incentives might make people scared to make mistakes.

There were times when I was deciding which route to take with my experiments and felt bad about choosing a route that used more waste, but was better for my project (BB 2917 where we have some choice in the experiments we use for a term-long project).
Not sure if monetary incentives are the best way to go about doing this, but I'm sure it would produce results.
It would make the procedures of the labs even more stressful since students would now have to worry about how much material they are using = loss of confidence.
Accidents do happen. I feel as though this would make me feel guilty for making any sort of mistake
The incentive is the grade. This almost makes it frowned upon to mess up and I don't think it is the correct way to incentivize students to produce less waste.
I think this is more likely to hurt students. They'll try to be overly conservative in their usage that it becomes an issue and results in many students using more.
We already have an incentive program called letter grades.
It is a good idea, but personally it would not help me limit how much waste I used in labs. My waste came from making mistakes in lab and having to re-do sections, not from a lack of motivation to limit waste. This may work for some students but it would not have helped me.
might ruin the integrity of the experiment
Incentives to reduce waste wouldn't help me if i didn't know how to reduce waste
The incentives don't allow much room for error, and doesn't help students learn from their mistakes.
In my experience, introductory classes have a set list of materials and/or chemicals that are being used. I didn't feel like I had to come up with different equipment or chemicals to work with for these labs. The items we worked with, all groups used. Some waste could have been prevented, but overall, I don't remember a lot of waste.
Still doesn't necessarily help if the students don't clearly understand the experiment procedure that leads to waste as they constantly redo the experiment.
Students might not be able to properly perform experiments if they want to have less waste to get a gift card
I feel like this is a good idea, but is not how a college level class should be taught
I think that this would encourage students to get the project done with as few materials as possible and cause them to be more careless making their data incorrect due to lack of want to use more materials.
I think giving students or the class bonus points on an assignment/their grade overall would be a much better incentive to use less waste than something like a gift card.
I think that this may take away from the focus on content during labs and more on using as few materials as possible.
I don't love this idea, perhaps making the incentive like, 5 extra points to bump your grade in the class, but mistakes do happen and I'd hate to penalize students for making mistakes
Most waste is created by accident. I personally do not need more motivation to not be wasteful.
It could increase stress and risk for contamination. When in doubt, throw it out.

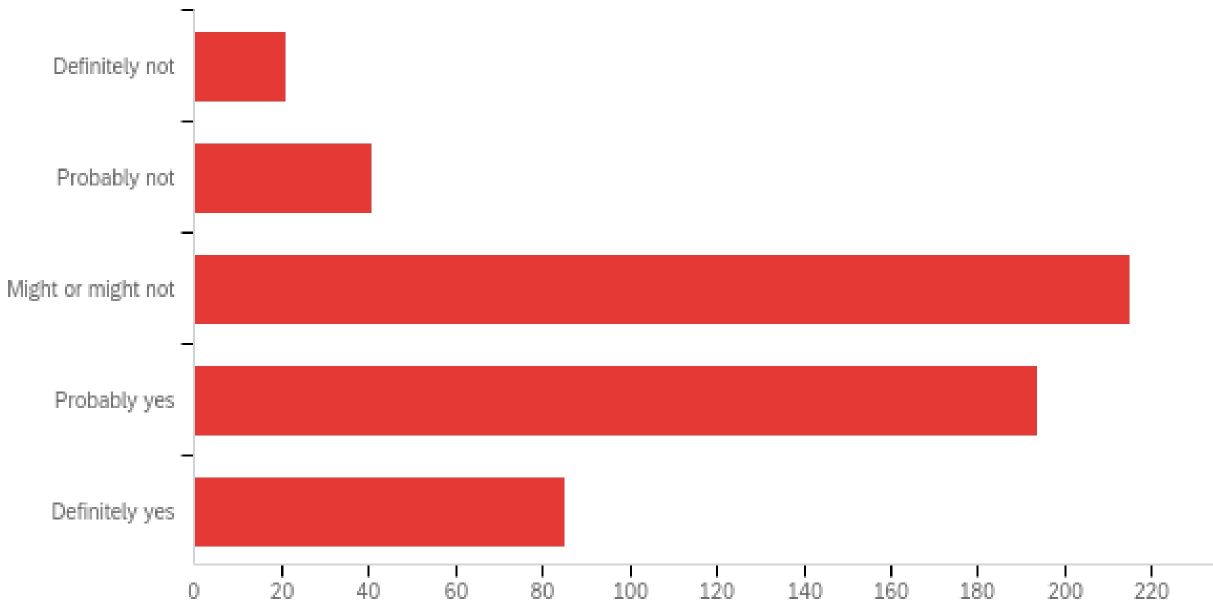
Good idea
I feel like incentives will probably not make a significant difference unless it was for doing something that is very clear and measurable. Simply "reducing waste'" seems to vague to provide a good incentive.
I think it would add a massive amount of inefficiency to all lab practices. Having to measure every material given out would suck and having a tiny reward for a massive effort of measuring every material is not motivating
Good performance in a chem lab should not be incentivized by a monetary reward
Reduced waste should be a class effort when working towards a reward, not group by group. Lab groups are randomly assigned and it seems unfair since some students are naturally going to end up with a less ambitious group than others. I think that would cause frustration. Some students may not care about getting a reward and that can ruin it for an entire group. Or, instead of one group receiving the reward, there is a goal in which any group can receive the reward. Such as "any group who uses less than __grams of silica will qualify for the reward."
I think this is a good idea, but could add stress to the class in making sure that not only we did the lab by itself, but now there's an extra task of limiting waste and that could be difficult to figure out on our own, causing more stress. I like the idea of a class reward though, maybe the whole classes getting an extra point or so somewhere if the waste goal is achieved.
I would probably sacrifice redoing a lab/getting good data and understanding in order to not produce more waste
The class as a whole might not react well if one group in particular caused them to go over the margin and therefore lose their reward.
I think there would be more focus on the competition and less on the actual point of the experiment. And by using too little some students may actually need to redo the experiment and use more materials
I think this would add more stress to the lab and students since they'd feel extra pressure for perfection.
Even with the reward I feel like every experiment still has X amount of waste that can't be avoided so something like this might just cause stress and group distress
I think monetizing it is a good idea in theory, but it could be create unhealthy competition. It may also discourage students who are already struggling further bc they need to use more material to redo something they messed up
System halving: homologous recombinant link vector can be system halving,
Teachers can adjust their own use time according to needs, and implement a strict registration system, we attach importance to the maintenance of instruments and equipment, functional development, so as to tap the potential of instruments and equipment, improve the management and use benefits of instruments
The establishment of the central laboratory in accordance with the principle of resource sharing, special management sharing, will be more advanced
I dislike depending on others to receive a reward. I would implement this per student or group, not for the whole class.

Mistakes are a catalyst for learning. Rewarding people for perfection is no different from punishing mistakes, because those who dare to learn miss out on the rewards. This is a terrible idea.

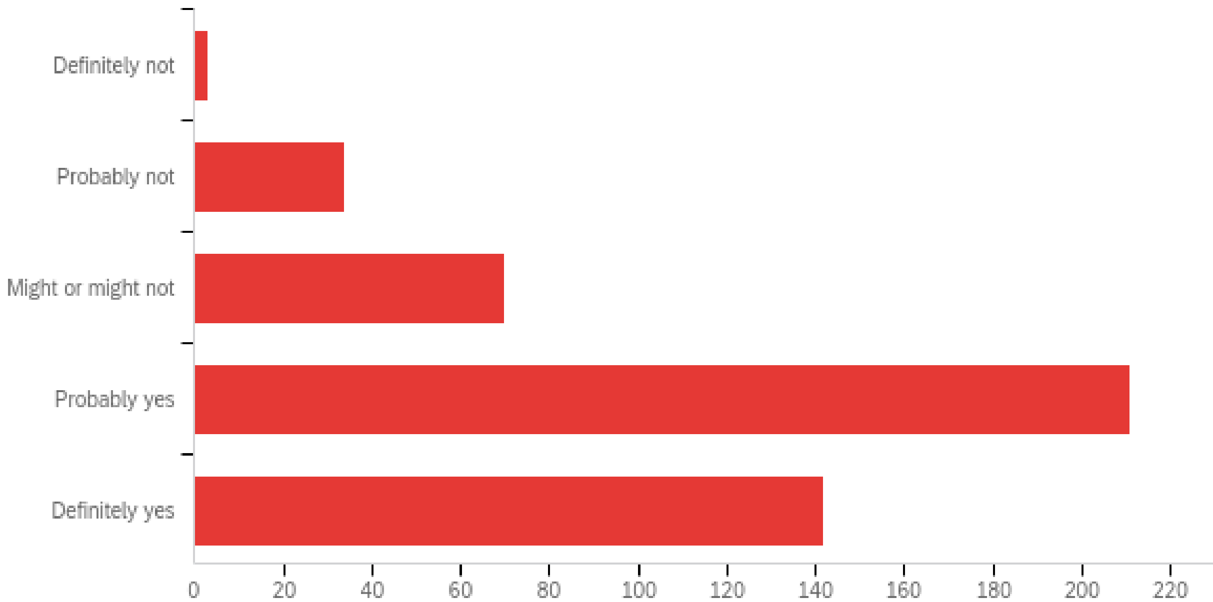
I think this would definitely be popular, but might cause students to sacrifice the quality of their experiments in an attempt to be more efficient. While incentives are usually a great tactic, the first idea about instructional videos would create a longer-lasting impact by helping students develop proper lab techniques, in my opinion.

It might encourage people to use materials even if they aren't perfect to reduce waste without considering how it will impact the experiment

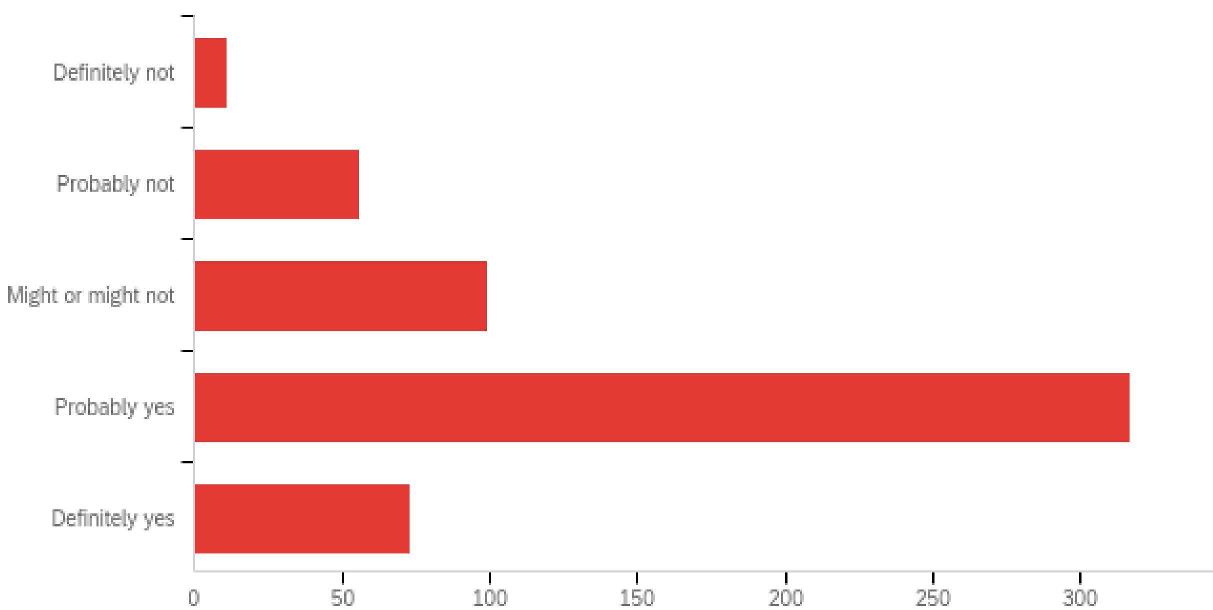
Q24 - Would you like if this idea was implemented in the introductory biology labs you've taken?



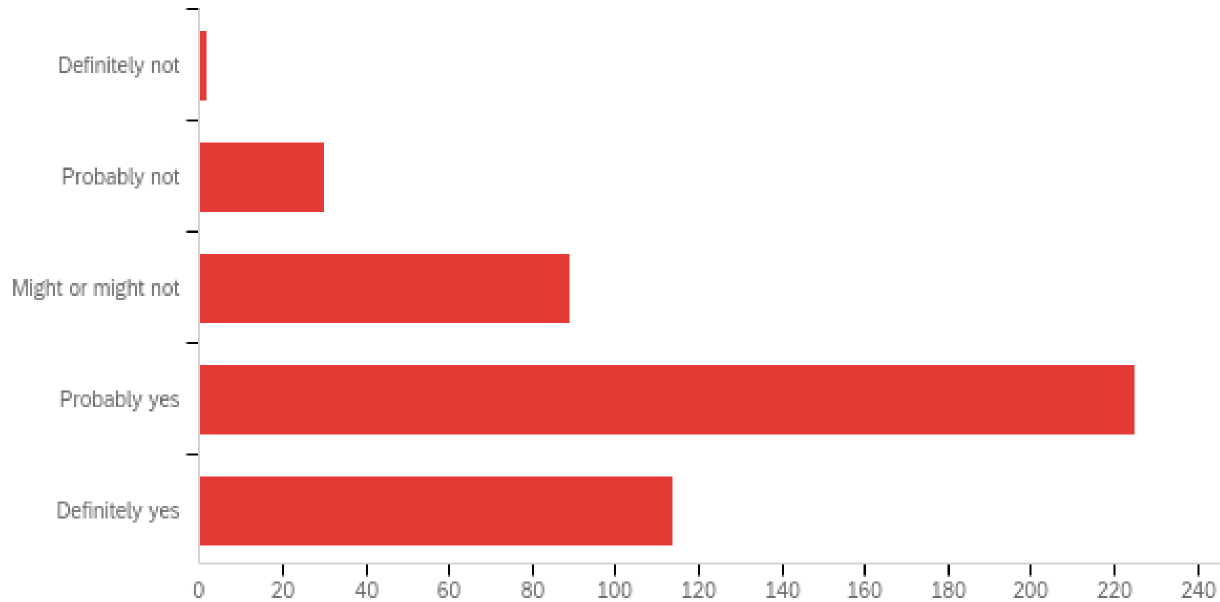
Q58 - Would you like if this idea was implemented in the introductory chemistry labs you've taken?



Q25 - If this idea was implemented in the introductory biology labs you've taken, would it have helped you reduce your waste output?



Q59 - If this idea was implemented in the introductory chemistry labs you've taken, would it have helped you reduce your waste output?



Q27 - (Optional) If you have additional thoughts on this idea, please write them here.

This could also teach people to not make more waste when in the work place after college!
This is probably the best / most feasible - especially since some instructors already do something similar and students would likely appreciate the guidelines.
Students wont pay attention
This is a great idea because it still allows students to experiment without wasting tons of tips.
Definitely good to be told when things are reusable, but I'd make it a note next to each resource on the lab doc rather than including it in the first day lecture.
It might make things more complicated since it's adding extra steps, so students might get confused
I feel that this is something that is already in place within the introductory chem lab courses. I thought my professors and TAs adequately demonstrated the procedures in class when necessary and often were able to provide notes on the necessary amounts of certain reagents. So, I think for this idea to be implemented with any observable effect, it would have to be expanded on to go beyond what is already being done.
Most lab professors already give you some numbers before lab starts, and then tell you to have trials with different variables to see how it affects the experiment, which I think is good for understanding the material.
Some students need these lessons
I think this is good. I do believe that maybe instead of being told how much reagents, we were maybe told "yes that's the right amount" or "no that's too much"
This seems like a much better idea, informing people beforehand so they're mindful of what they should be using. It allows for mistakes, but they at least know directives on normal amounts and can try to reach those outputs.

I like that this allows the instructor to participate in determining where it is realistic to avoid unnecessary waste. This puts less pressure on students and avoids uncertainty, preventing needless assumptions.

This is recommended and I agree with it

It is good that the waste in the experiment is disposed of properly

In person discussions/demos of this would be very helpful for informing the class of ways to reduce waste!

This was the kind of thing I thought about during lab, but I didn't always know how to implement it or if materials could be reused. Sometimes I could ask the TA or instructor but not always. This is an easy way to be empowered and informed about reducing waste in lab

another good idea that students could easily ignore if they do choose leading to no change in waste

I really like this idea

So far, I think this is the best procedure to enact.

Lab time is already very valuable and spending large amounts of time on how to reduce waste will hurt students learning

didn't use pipettes

I would definitely like this because thinking back, there were a lot of times where we needed a chemical in excess, and it would be good to know through guidance how much is excessive and how much would be good for a successful experiment.

the image is a bit confusing but I think the idea of explaining the quantities generally would be very helpful

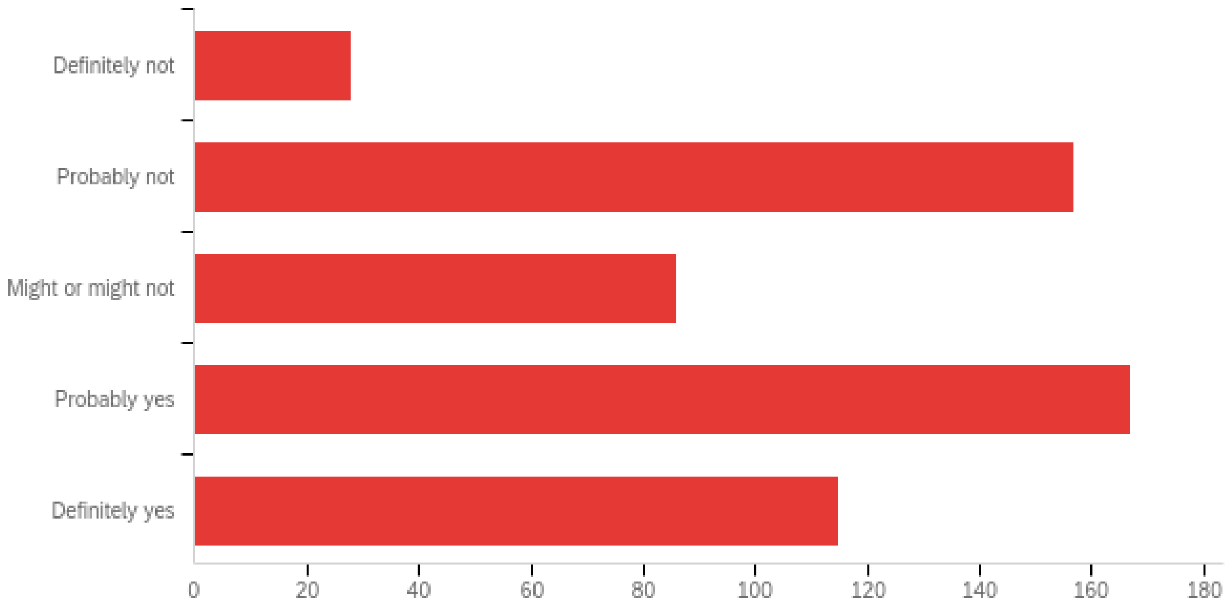
Provides recycling programs for a variety of products including gloves, pipette suction boxes, shipping boxes, plastic bags, plastics

Here is to share with you the lab might use to save money tips: youdaoplaceholder9 system halving: homologous recombinant link carrier can be system halving, effective pro - testing.

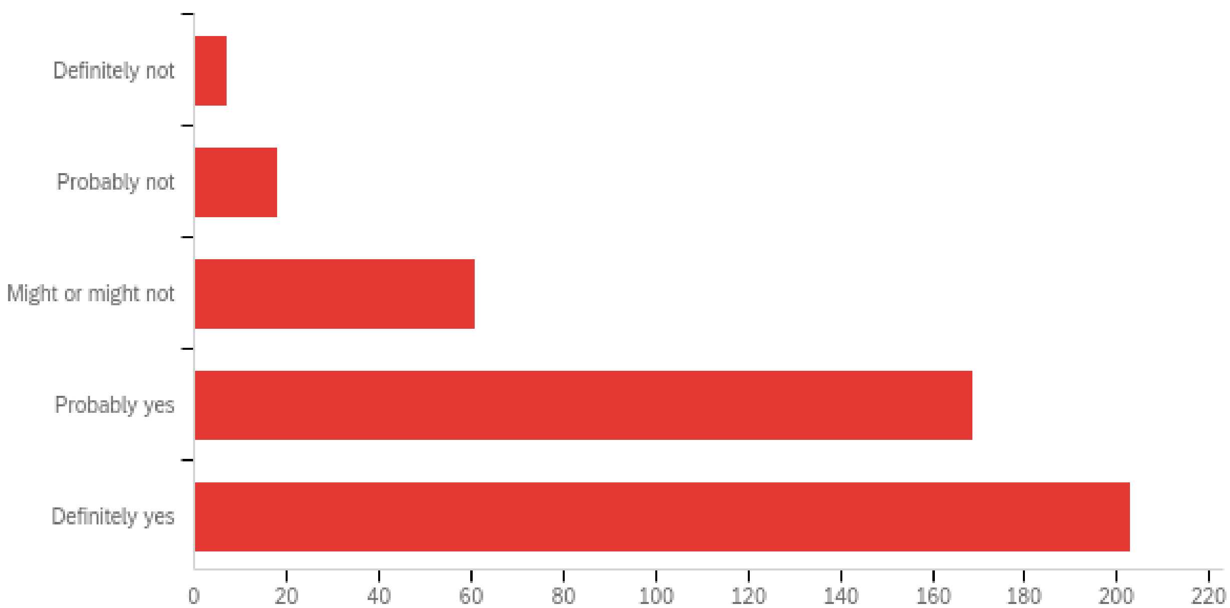
I think this would be a great way for students to understand the impact of lab waste and the importance of reducing it. It would be a good motivator for them to take action in this lab and possibly other labs in the future.

In theory has practical, real world applications since less waste also saves money in a work setting

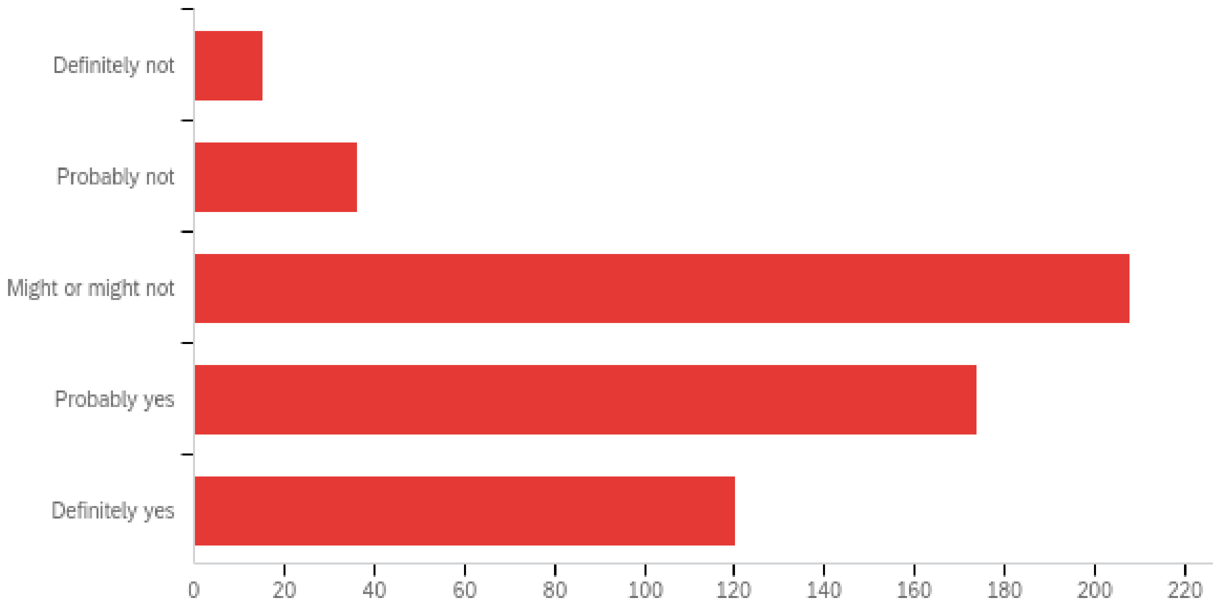
Q34 - Would you like if this idea was implemented in the introductory biology labs you've taken?



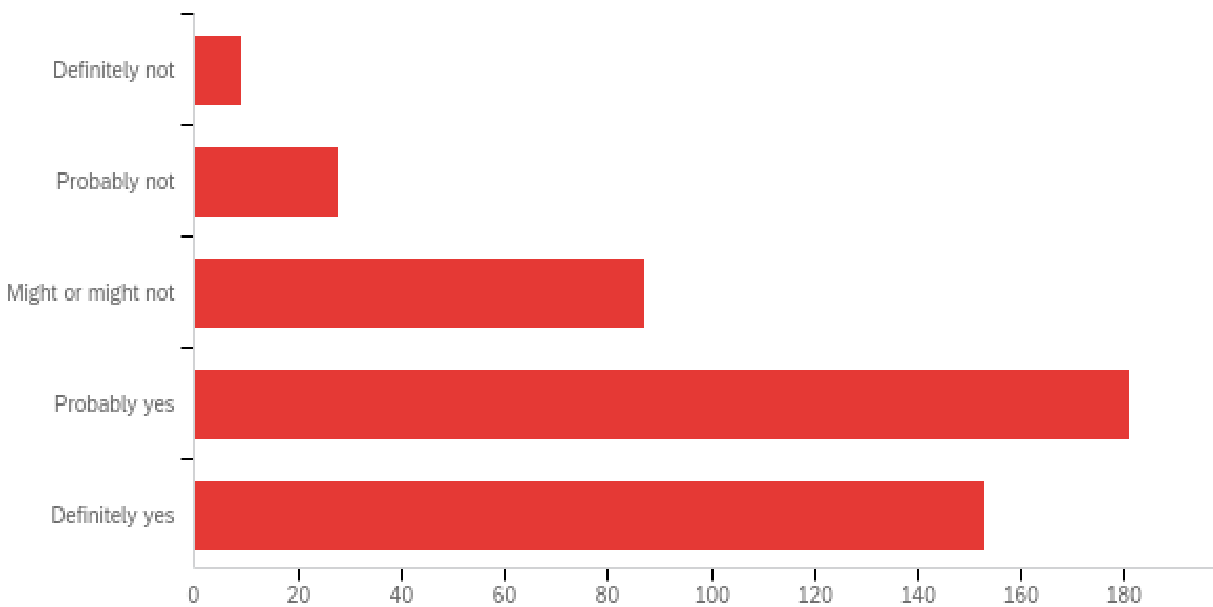
Q60 - Would you like if this idea was implemented in the introductory chemistry labs you've taken?



Q35 - If this idea was implemented in the introductory biology labs you've taken, would it have helped you dispose of waste properly?



Q61 - If this idea was implemented in the introductory biology labs you've taken, would it have helped you dispose of waste properly?



Q36 - (Optional) If you have additional thoughts on this idea, please write them here.

I often found myself asking a TA where to put my waste, just to be sure. It'd be easier to look at a poster.
I have only taken Chemistry labs. I feel like this idea might help me reduce waste. This is because my instructors had outlined beforehand how to dispose of waste and I was able to remember their instructions.
this guide is a bit overcrowded and convoluted. It would be more effective if it was simpler.

I think it would be interesting/instructional to show/list the ending result of the waste. For example: the broken glass in the box goes to a recycler who adds it as filler in pavement
It is nicer than having to ask the professors and TAs about everything.
Well, it depends on the individual
But some people just like to be upset by the rules
This would be helpful in general, though idk about it's helpfulness towards preventing unnecessary waste.
This idea already exists and is implemented
Type of thing that makes sense but nobody would ever read
It is good that the waste in the experiment is disposed of properly
Minimize waste in the experiment
Good advice to promote the efficiency of doing research and all aspects
The method is uncertain and not applicable
That's a good idea
Although this was a strong point made in each lab, having a sign like this right next to the waste disposal bins could only benefit the waste disposal process and most likely reduce improper disposal overall.
Definitely useful and there's a need for this. My CH1010 class always got yelled at for disposing the glass tubing with their plastic caps in the glass waste bucket (because the school had to pay extra since it wasn't only glass in there)
I probably asked my TAs once per class period where to put some type of waste. It's hard to remember when you're new.
Sometimes people dont take the time to read poster properly
Too many words, make it look more visually appealing so people are prone to pay attention and read it/look at it
Figuring out where to dispose of different types of waste was one of the hardest parts of my first bio lab!!! I was constantly unsure and having to interrupt what I was doing to ask how to dispose of things. Pictures or descriptions of what goes where on/near each disposal container might also be helpful.
If these are not pointed out, a lot of people probably will not notice them.
Poster not detailed enough for Chemistry labs
i did not take a biology lab, might an error in the survey! also i think there might already be posters but there are so many posters in the labs it might be negligible
Assuming for the second question it meant chemistry as I have not taken biology at WPI
The poster is really busy, is there a way to reduce the words and make it easier to look at?

I think this one is the best so far. Its easily available when you need it and takes 30 seconds to read the whole thing
too many words and pictures, very confusing
Poster is cluttery and too long, I probably wouldn't read it
I would have liked this a lot, because when I took my chemistry class I was often confused on what to do with the waste or how to dispose of it and put that on my partners instead.
This in combination with the incentive would be a good combination
Provides recycling programs for a variety of products including gloves, pipette suction boxes, shipping boxes, plastic bags, plastics
The principle of joint management will be more advanced
Expensive instruments are managed by special personnel and placed in the central laboratory
I would've loved to have a reference like this
I think this is something that should be implemented regardless and could be done in conjunction with another proposed idea. I would recommend a simplified poster compared to the example provided so students aren't deterred from reading it, but this seems like a great resource
This isn't already implemented? What is the chemistry department doing?

Appendix I: Questions for EHS

Below lists the exact questions we asked the WPI Environmental Health & Safety (EHS) representatives during our interviews.

1. How does WPI currently handle all the waste from the teaching labs – how is it collected and what happens to it?
2. In your opinion, what is the most harmful form of waste generated in WPI's teaching labs (e.g., plastic, glass, certain chemicals)
    a. How harmful has WPI's waste been?
    b. We would like to evaluate the amount of chemical waste WPI's teaching labs generate (particularly introductory chemistry and biology labs)
        i. Could EHS have provide us with data regarding this, or know where we could find it?
3. What solutions have been implemented in the past to reduce teaching lab waste at WPI?
4. Would our working solutions to reduce waste in WPI's teaching labs be practical? (See below)
    a. **1. Experimental Tutorials:** After an experiment's pre-lab is due, but before class, videos are unlocked on Canvas that demonstrate how to perform the lab techniques used by the experiment. Everything is kept very general in the videos as to not simply give the students the experiment's entire procedure. We hope these videos will decrease student error in experiments, leading to less waste.
    b. **2. Waste Reduction Instruction:** At the start of the lab course, lectures are provided that explain how to reduce waste. For example, they could detail when it is okay to reuse something, explain how to ensure you don't take more than you need of some reagent, etc. Each lab, instructors or TAs also tell students roughly how much of each material/reagent they should be using, and any tips to use less. Instructors or TAs may also inform students on the impact of generating excess waste to provide them with greater motivation.
    c. **3. Incentivization Programs**: Programs are developed in which students are given rewards (e.g., gift cards) for using less materials and reagents in experiments. This could involve all students getting a reward if the class as a whole doesn't exceed some waste threshold, or only the most efficient students could be given rewards.
    d. **4. Waste Disposal Posters:** Posters are hung in the lab classrooms that outline which container each possible piece of waste should go in. While this may not reduce the actual amount of waste students generated, we hope these posters will ensure waste is always placed in the right container.
5. Is EHS responsible for producing lab safety videos or instruction for students in teaching labs?
    a. If so, would EHS be opposed to including additional instruction of waste reduction practices in these videos/instructions – this could be a part of Solution 2

6. How is the current recycling process structured at WPI – what from the teaching labs gets recycled?
7. Would EHS be willing to work with us to implement recycling programs such as nitrile glove recycling?
8. Would WPI be willing to pay more for sustainable materials for their teaching labs?
    a. E.g., glass materials (like glass Petri dishes), bioplastics

Appendix J: Lab Observation Procedures

In this appendix section we have pasted the procedures we followed for each of our lab observations. We used a separate procedure for the three different classes we observed (CH1010, CH1020, BB2915), though each is very similar.

Procedure for Observing CH1010

The CH1010 classes will be doing the Quantum Dots Lab, the protocol and waste products of which are detailed in the below sections. Two people will actively observe each class at a time, both of whom should take notes on the points listed below. Do not inform anyone (students, instructors, or TAs) on what exactly you're notating to prevent biasing their behavior.

1. *Student waste reduction*
   a. Is the teaching staff (i.e., the professor + TA) putting any emphasis on waste reduction?
      i. Do they indicate how much of each chemical and material students should be using?
      ii. Do they give students tips or instruction on how to minimize their waste output?
   b. Do you notice any instances of students performing actions that result in unneeded waste?
      i. *This includes:* breaking glassware, spilling chemicals, needing to redo parts of the experiment, using more single-use items or chemicals than they need
         1. For what's considered "more than they need," see "Waste in Quantum Dots Lab" below
      ii. Pay close attention to how much oleic acid students grab from stock solutions: they should ideally grab no more than ~0.6 mL more than what's needed for the experiment
      iii. Also pay close attention to if students repeat their experiment because of the duration of time samples were taken (*if students do not notice a difference in color in their samples, there will be no difference in absorbance while using the spectrometer, causing them to redo the reaction)*
2. *Proper waste disposal*
   a. Do the labs have any posters or signage indicating where waste products should go?
      i. If they do, take pictures
   b. How are waste receptacles (e.g., trash bins, chemical waste jugs) labeled, and is this labeling clear?

        i. Take pictures of this
    c. Are students disposing of their waste in the correct locations?
        i. Try and record how often students make errors regarding this, if at all
        ii. See “Waste in Ideal Gas Lab” below for information on where the waste should be going
3. *Other information*
    a. Write down how many students are in the lab, and how many lab groups there are
    b. Record any other information you feel is relevant to our IQP

Feel free to take notes however you want (e.g., on paper, on your phone, etc.). We’ll collate all our notes into a single document sometime later.

Also, promote our TA/Professor survey to people in the lab preferable sooner rather than later. Let them know that the department head said the department was “not interested in completing our surveys,” but welcome them to fill it out anyways. Bring a printed QR code with the survey link and offer to email it to them if they would prefer that.

CH1010 Lab Protocol

In order to produce CdSe (cadmium selenide) nanocrystals, a stock solution of Se is prepared from 30 mg of Se and 5 mL of 1-octadecene. This is done in a 10-mL round-bottom flask clamped over a hot stirrer plate. Using a syringe, measure 0.4 mL of trioctylphosphine (do this from the Sure-Seal bottle) and add it to the 10 mL flask. Add a magnetic stir bar to mix the solution, but it may be beneficial to speed the dissolution of Se. This should be stored at room temperature, and it will be enough for 5 Se (selenium) precursor preparations.

Using a heating mantle, add 13 mg of CdO (cadmium oxide) to a 25-mL round-bottom flask. In that same flask, 0.6 mL of oleic acid and 10 mL of octadecene are also added. A thermometer that should measure 225°C is inserted. Once it reaches 225°C, 1 mL of the room temperature selenium solution is added to the flask. At this point in the lab, the student should begin timing the solution, since the characteristics of the products depend on reaction time. Using a 9-inch Pasteur pipet, remove 1-mL samples as quickly as possible at different time intervals. These samples should be taken during the time when the selenium solution is added and when the notable color change of the solution occurs later. The goal is to obtain nine or ten samples within two to three minutes. Your samples should range from yellow to red. The samples are then be added to 1-cm glass small-volume cuvettes to observe the absorption and emission spectra of each sample.

Table G1: Description of where each CH1010 waste item should go.

Item	Quantity per Lab Group	Proper Disposal Procedure	Other Notes
Selenium	30 mg	Waste disposal container	This should **NOT** be dumped down the drain
Octadecene	15 mL	Waste disposal container	This should **NOT** be dumped down the drain
Trioctylphosphine	0.4 mL	Waste disposal container	This should **NOT** be dumped down the drain
Cadmium Oxide	13 mg	Waste disposal Container/do not mix with other wastes	This should **NOT** be dumped down the drain/should be left in original container
Oleic acid	0.6 mL	Waste disposal container	This **SHOULD NOT** come in contact with raw sewage or water (**no drain**)
Cadmium selenide	9 or 10 1-mL samples	Waste disposal container	This should **NOT** be dumped down the drain
Pasteur Pipet	9-inch	Sharps box, broken glassware disposal bin	This is not what our focus should be on

Procedure for Observing CH1020

The CH1020 classes will be doing the Ideal Gas Lab, the procedure and waste products of which are detailed in the below sections. 2 people will actively observe each class at a time, both of whom should take notes on the points listed below. Don't inform anyone (students, instructors, or TAs) on what exactly you're notating to prevent biasing their behavior.

1. *Student waste reduction*
    a. Is the teaching staff (i.e., the professor + TA) putting any emphasis on waste reduction?
        i. Do they indicate how much of each chemical and material students should be using?
        ii. Do they give students tips or instruction on how to minimize their waste output?

b. Do you notice any instances of students performing actions that result in unneeded waste?
    i. *This includes:* breaking glassware, spilling chemicals, needing to redo parts of the experiment, using more single-use items or chemicals than they need
        1. For what's considered "more than they need," see "Waste in Ideal Gas Lab" below
    ii. Pay close attention to how much HCl students grab from stock solutions: they should ideally grab no more than ~2 mL more than what's needed for the experiment
    iii. Also pay close attention to if students use DI water instead of tap when creating their apparatuses *(the production process of DI water is more wasteful than tap, so unneeded use of DI water is bad)*

2. *Proper waste disposal*
    a. Do the labs have any posters or signage indicating where waste products should go?
        i. If they do, take pictures
    b. How are waste receptacles (e.g., trash bins, chemical waste jugs) labeled, and is this labeling clear?
        i. Take pictures of this
    c. Are students disposing of their waste in the correct locations?
        i. Try and record how often students make errors regarding this, if at all
        ii. See "Waste in Ideal Gas Lab" below for information on where the waste should be going
3. *Other information*
    a. Write down how many students are in the lab, and how many lab groups there are
    b. Record any other information you feel is relevant to our IQP

Feel free to take notes however you want (e.g., on paper, on your phone, etc.). We'll collate all our notes into a single document sometime later.

CH1020 Lab Protocol

This experiment used 3 different metal samples (zinc granules, aluminum foil, and magnesium strips) and 2 M HCl. An ideal gas apparatus also needed to be prepared before for the experiment. To create this apparatus, rubber tubing was first attached to a rubber stopper via a plastic adapter. The connection between these items was then made air-tight using Parafilm. Next, a 1 L beaker and 100 mL graduated cylinder were filled with water. The top of the graduated cylinder was then sealed with parafilm. Following this, the graduated cylinder was placed in the 1 L beaker (Parafilm side facing down) and clamped in place. The parafilm on the graduated cylinder was then removed using forceps. After this, the forceps and paperclips were used to move the rubber tubing's open end into the beaker and up to the top of the graduated cylinder. The apparatus was now complete.

A 125 mL Erlenmeyer flask was filled with about 25 mL 2 M (aqueous) HCl and one of 3 metal samples (Zn, Al, or Mg). The metal samples were measured using an analytical balance and weigh boats to be .081 g for Mg, .218 g for Zn, and .060 g for Al. Once the metal was added to the HCl in the flask, the stopper from the ideal gas apparatus was quickly placed over the flask's opening. Inside the flask, the metal reacted with the acid to create metal-chloride salts and H2 gas. The H_2 gas moved through the tubing connected to the stopper, depositing in the 100 mL graduated cylinder. The reaction was done for each metal separately and took around 5 minutes each time.

For each trial, the volume of gas initially in the graduated cylinder (ideally 0 mL) was subtracted from the volume after the reaction to get the volume of gas the reaction added to the cylinder. This volume was converted into pressure using the ideal gas law. The partial pressure of water was then subtracted from this number to get the pressure of just H_2 in the cylinder. This value was taken as the pressure of H_2 gas created by each reaction. These pressure values were used to determine the percent yields of each reaction.

Table G2: Description of where each CH1020 waste item should go.

Item	Quantity per Lab Group	Proper Disposal Procedure	Other Notes
Water	~1 L	Down drain	This is the water used within the gas apparatus. This should be tap water, not DI
Post-reaction solutions	~75 mL	Solutions will be highly acidic (pH < 1) and too large in volume to reasonably dilute. Should be neutralized with a base (to pH ~5.5) and poured down drain. This will likely be handled by the TA (i.e., students should hand off these solutions to the TA) *Note that some solutions will contain $AlCl_3$ (highly toxic), but this should react with water while in the solution to form non-toxic products*	These solutions should contain some metal chlorides, HCl, and maybe some unreacted solid metal (all in water)
Parafilm	4 or 5 squares	Normal trash	This is used to assemble gas apparatus
Weigh boats or paper	3 boats or paper	Normal trash	These are used to weigh out metals

Procedure for Observing BB2915

Students will be performing various experiments on bacterial colonies that they have grown from a soil sample. The goal of the lab is to research the bacterial colonies for antibiotic production or antibiotic resistance. The class as a whole will be performing many different experiments all at the same time. At the time of observation, students will mostly be working with microscopes, performing gel electrophoresis, preparing for PCR, and extracting products from their bacteria.

1. *Student waste reduction*
    a. Students will often have to work over a lit Bunsen burner to remain aseptic. Take note of students who keep the burner on while not working above it.
    b. Glass test tubes should be returned to the Dirty Dishes Bin and **not** thrown away unless broken.
2. *Proper waste disposal*
    a. Do the labs have any posters or signage indicating where waste products should go?
        i. If they do, take pictures
    b. How are waste receptacles (e.g., trash bins, chemical waste jugs) labeled, and is this labeling clear?
        i. Take pictures of this
    c. Are students disposing of their waste in the correct locations?
        i. Try and record how often students make errors regarding this, if at all
        ii. See "Waste in Solutions in Soil" below for information on where the waste should be going
3. *Other information*
    a. Write down how many students are in the lab
    b. Record any other information you feel is relevant to our IQP

Feel free to take notes however you want (e.g., on paper, on your phone, etc.). We'll collate all our notes into a single document sometime later.

BB2915 Lab Protocol

1. Gram staining
    a. Students place a colony onto a glass microscope slide using an inoculating loop/toothpick. They then cover the slide in different dyes to stain the bacteria. They observe this slide under a microscope. **Glass slides are biohazardous sharp. Students can rinse the dying stations into the sink.**
2. PCR preparation
    a. Students boil and freeze cells from their colony several times. They then add several primers and dyes to this mixture and place it into the PCR machine. **Tubes created during this experiment are biohazardous.**
3. Gel electrophoresis
    a. Students retrieve the electrophoresis machines from under their bench. They pour agarose gel into the receptacle, wait for it to harden, and then pour buffer over the gel so that it is fully covered. They micropipette in their samples and run the machine for 20-60 minutes. **Students should pour this into the sink when finished and dispose of the gel into the biohazard cardboard box. The receptacle should then be rinsed with distilled water.**

4. Extraction
    a. This experiment has 4 parts that each take place on a different day. The specifics aren't important, but students will create **organic waste that goes into a liquid waste container located in the fume hood**.
5. Miscellaneous tests
    a. There are ~4 very short tests students can do to learn properties of their bacteria. These mostly involve putting a chemical onto a bacterial sample or growing the bacteria on a special Petri dish/medium.

Table G3: Description of which items should go in each waste container in BB2915.

Waste Container	Description	Examples	Other Notes
Biohazard (small bags)	The small bags above the bench are for biohazard non-sharps. They should contain small objects that cannot puncture a plastic bag. Generally, they are items that are not sharp and cannot become sharp.	Micropipette tips, small plastic test tubes, toothpicks, inoculation loops, etc.	These bags are meant for small items only. Large items like plastic gloves/paper towels fill up the bag easily and cost WPI more money.
Biohazard (large box)	At the front of the room below the whiteboard, there is a large cardboard biohazard box. This is the same waste stream as the small bags on the lab bench, but it is meant for larger items. Biohazardous gloves should go in the box, along with other large items like Petri dishes.	Gloves, biohazardous paper towels, Petri dishes, electrophoresis gels, etc.	Small items can go into this box as well if needed. Students should remove their gloves above this container and place them inside.
Biohazard sharp	Next to each bench is a red plastic box. This is where biohazardous sharps go. Sharps are items that can puncture a plastic bag. Generally, they are items that are sharp and can become sharp.	Pipettes, glass microscope slides, broken glass test tubes, etc.	Only sharps should go into these containers. It is a waste for non-sharp items to be disposed of into this container.
Dirty dishes bin	A gray bin located on the central lab table. All washable and reusable items should go into this bin.	Glass test tubes, metal spatulas, empty glass bottles, etc.	TA's wash these items and they are reused for next class.
Normal trash	The regular trash where non-biohazardous materials can go.	Paper towels, tape, plastic bags, etc.	-