SUSTAINABLE SCIENCE

SINGLE-USE EQUIPMENT

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ABSTRACT

This paper is an exploratory study into sustainability issues in laboratories with a focus on single use material waste, often referred to as 'lab plastics'. The paper takes a qualitative approach to understand the barriers, equipment, behaviours and systems involved in this topic through a literature review, online surveys and semi-structured interviews with laboratory users and goods manufacturers. This study takes a designer frame of reference and aims to identify opportunities that could serve as important contexts to design products or systems that can improve laboratory sustainability. Recommendations are presented to highlight examples of how these opportunities could be addressed.

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1.0 INTRODUCTION

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1.1 INTRODUCTORY STATEMENT

The aim of this thesis is to understand the experiences of researchers while interacting with disposable equipment and the effects that regulations and occupational health and safety (OHS) have on the viability of sustainability improvements on these experiences. Points through this understanding that are determined to be addressable and will have a significant impact will be chosen to design products that will improve sustainability of laboratories.

1.2 SUSTAINABILITY IN LABORATORIES

Science is a large part of modern life and has brought people research and developments that have saved lives, improved the world and more. However an issue within laboratories is the excessive waste produced. Many believe this is the cost of progress in the 21st century, though the scientific community that uses laboratories are not comfortable with the state of sustainability in scientific lab work as it exists. This is shown through survey results of Wright et al (2008) and social media trends such as “#SustainableScience” and “#LabWasteDay” (Howes, 2019; Exeter, 2019).

Many laboratories are required by national regulations to be extremely cautious of possible contamination, biosecurity, risk of infection and other factors that could be hazardous to the environment and to people (OGTR, 2012). This has resulted in scientists and researchers relying heavily on plastic equipment in their daily routines and items that could have been reused, recycled or are not appropriate to dispose of being disposed of very quickly after use.

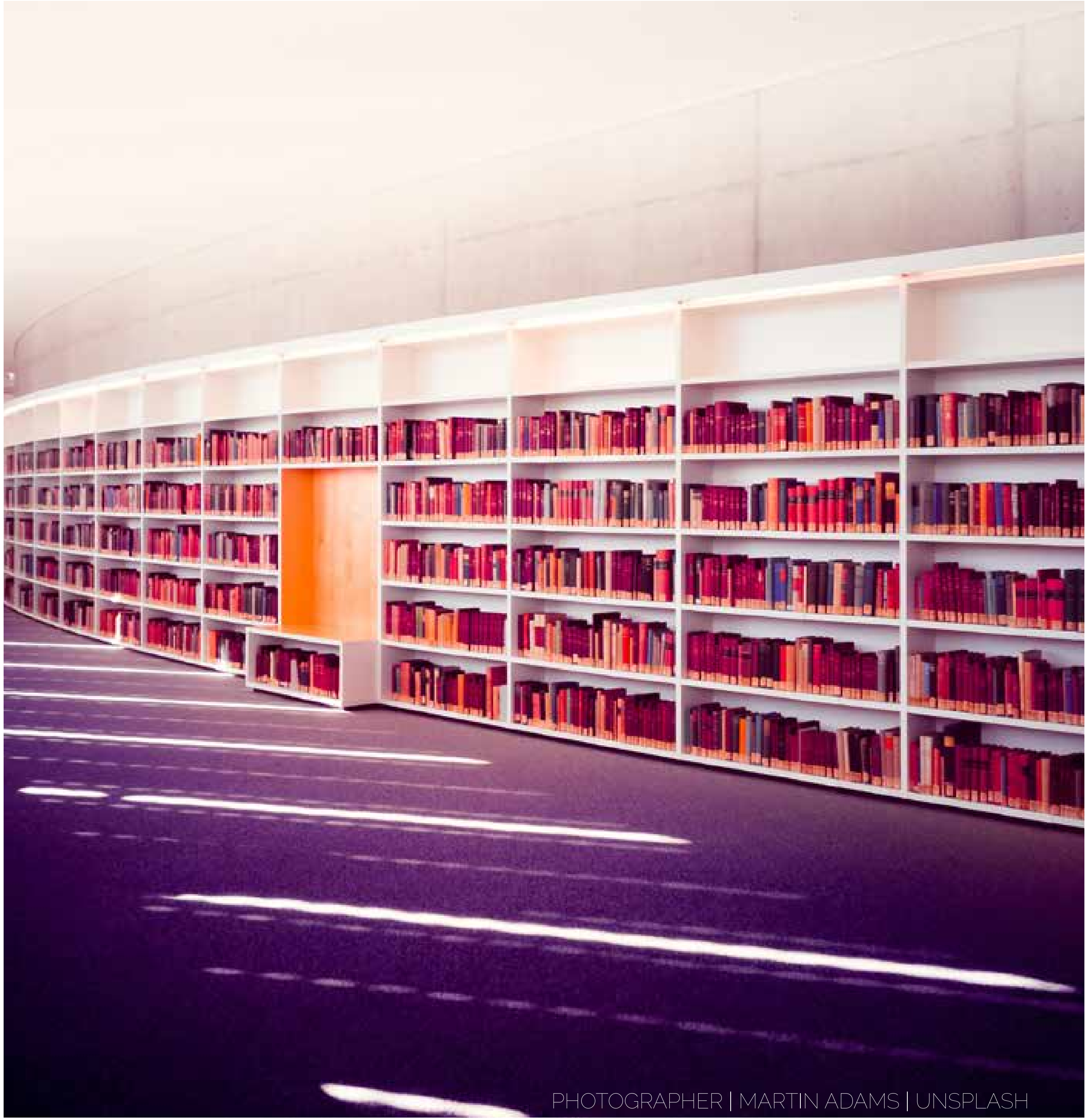
The amount of plastic waste produced in a year by a medium laboratory is about 267 tonnes as environmental scientists’ Urbina et al. (2015) at Exeter University estimate.

Many materials are not appropriate for decontamination, which would have allowed them to be recycled and must be disposed of through other methods that release toxic fumes and gases into the ecosystem and chemical waste ending up in waterways (Ross et al, 2019).

Figure 1 outlines the structure of the following thesis on sustainability in laboratories.

Figure 1: Paper Structure.

2.0 LITERATURE REVIEW



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This literature review identifies information regarding sustainability in laboratories with a focus on material waste and single use items. Discussing how it affects the environment, organisations, what materials are wasted, how it is disposed of, the barriers to sustainability in a laboratory.

2.1 LABORATORY SUSTAINABILITY

Sustainability is becoming increasingly important with severe impacts on the environment and society for inaction. Consequences include, global warming, changing sea levels, changes in ecology and diseases, scarcity and loss of irreplaceable resources, buildup and production of physical waste and decreased biodiversity among others (NASA, 2020).

Laboratories in bioscience industries contribute heavily, My Green Lab (2020) (a charitable organisation for improving sustainability in science) describing laboratories as “one of the most resource-intensive spaces in any industry”. Functioning laboratories cover many needs in society and are the backbones of R&D in many sectors, taking forms such as independent laboratories, research associations, university laboratories, clinical/medical and private research and development. What the laboratory studies affects their sustainability choices and behaviors heavily, due to different requirements, standards, laws and workplace health and safety (WHS) (Holstein & McLeod, 2013).

Standards in place that Australian laboratories have to adhere to include the Physical Containment (PC) levels specifications by the Gene Technology Regulator. Levels range from 1-4 and relate to containment requirements of genetically modified organisms and types of dealings. Table 1 shows the levels and what they relate to, with PC level 1 being the lowest risk and PC 4 being the highest (OGTR, 2012; Australian/ New Zealand Standard, 2010 35-37).

Figure 2: PC Levels and requirements.
Information sourced from Dept. of Health, Office of the Gene Technology Regulator 2012 and AS/NZS 2243.3:2010 Laboratory safety standards.

Higer PC levels require heavy use of disposable equipment and safety protection with immediate disposal after use to contain GMOs and protect researchers, the community and the environment.

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For a market based approach Newswire (2016) has categorized laboratory equipment end-users into research & academic institutes, contract research organisations, hospitals & diagnostics centres, pharmaceutical & biotechnology industries and food & beverage industries. They identify research & academic institutes as the largest segment of the market, this could be due to the amount of government funding supplied to academic institutes for research that enables a wide range of study (Holstein and McLeod, 2013).

2.2 ENVIRONMENTAL MANAGEMENT SYSTEMS

One of the most effective and implementable strategies that organisations are using is integration of environmental management systems (EMS) and lean manufacturing approaches.
These have tangible benefits, including reducing the environmental footprint, cultural changes and financial performance of a business (Harris et al, 2011).

Lopez and Badrick (2012) detail in their paper “Proposals for the mitigation of the environmental impact of clinical laboratories” that medical laboratories need to be accredited with the ISO 14000 quality management system (QMS) standard in Australia (ISO, 2012). An EMS can be integrated into this system as they both share similar qualities allowing their management system to provide significant benefits in sustainability while reducing the procedures and bureaucracy required to make a change through a systematic response.

Ross et al (2019) further show successful integration of an EMS through the RCPAQAP group in 2015. Their process involves a senior management ‘green team’ identifying factors that will heavily impact the sustainability of the organisation and using the suggestions from Lopez and Badrick’s paper within the reduce, reuse, recycle framework to address them. Major progress is made in energy consumption, paper usage, postage and logistics automation reduction in plastic, resulting in business savings of $800000 over 3 years.

Laboratories are sophisticated and complex environments that collectively contain thousands of specialist scientific technologies such as fume hoods, autoclaves, centrifuges, laminar flows, spectrophotometers, polymerase chain reaction (PCR) machines and large temperature controlled rooms. The amount of sophisticated machinery and equipment is increasing with the adoption of robotics, synthetic biology, AI and machine learning and changing biosafety standards (Betz et al, 2018 95). These special environments result in creation of unsustainable practices like excessive energy use, material waste, biological waste and water waste that are not nearly as severe in traditional offices and other industries.
Laboratories typically have an energy consumption 4-5 times that of a comparable commercial office building (Wright et al, 2008) with cleanrooms

reaching 10-100 times higher (Lopez and Badrick, 2012). This is because the lighting, air conditioning, maintaining equipment and largely, because of the need for ventilation systems and fume hoods for removing hazardous fumes that are permanently active. This adds heavily to the cost of running the organisation and strain on energy production, unless a reliable renewable energy source is available and affordable. Measures can be taken such as using sensor lights, replacing fluorescent bulbs with energy rated LED bulbs, altering air conditioning settings to run primarily in freezer rooms and intermittently across the facility, closing the fronts of fume hoods when not in use, and switching off devices when not in use. The effects of these changes can be seen in Ross et al (2019) study shows through these efforts only a slight improvement in energy use is achieved (Figure 3).

Figure 3: Change in electricity usage for RCPAQAP Group.
Ross, Penesis & Badrick (2019).

There are many existing solutions to improving energy consumption and this is at the front of many organisations priorities as there are direct cost savings and solutions available.

2.3 USER MOTIVATION AND ATTITUDES

The motivations behind these changes are growing social and corporate responsibility, highlighting the environmental and ecological impacts that businesses and individuals have on the planet (Przychodzen J & Przychodzen W, 2015). Many scientists desire a shift away from single use-plastics to reduce their daily waste due to society's paradigm shift towards sustainability. Wright et al (2008) finds in their survey of laboratory researchers that almost three quarters state that they "were not conducting their research sustainably" with 93% of this group disagreeing with the following statements:

Scientific research should be exempt from sustainability issues;

research conducted in a sustainable manner is second class research;

one sustainable person cannot make a difference.

This is particularly prevalent for younger researchers in the community (Howes, 2019). To spread awareness people have used social media trends and campaigns. One such campaign started by eLife in the University of Exeter is "Lab Waste Day" (Exeter, 2019), encouraging researchers to gather all of their single use plastic containers and gloves, weighing the waste and posting it to social media under the hashtags "#labwasteday" and "#sustainablescience" (Shown in Figure 4).

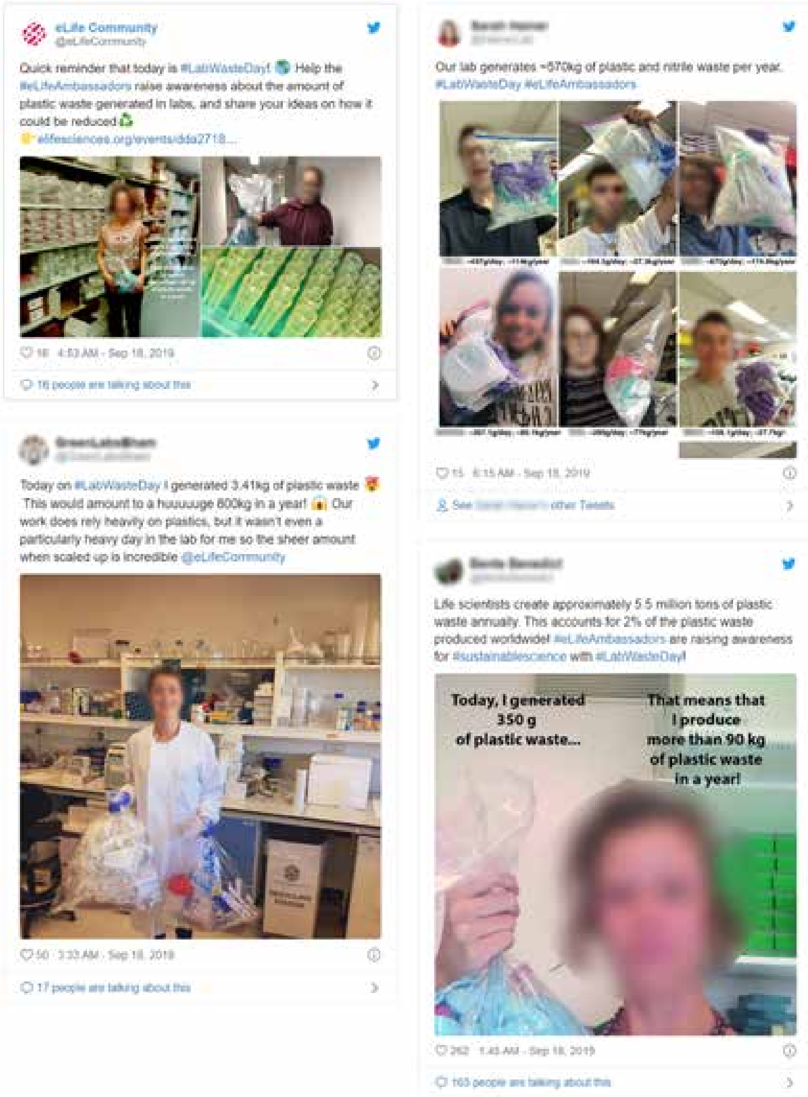

Figure 4: Social media posts for eLife #LabWasteDay 2019.
Sourced from Twitter, links in appendix.

2.4 REDUCE, REUSE AND RECYCLE

The most widespread and diverse principle of the 3R's "reduce, reuse, recycle" that most users follow in their personal lives run into many barriers within a laboratory environment. There is some conflict between the belief that a broad, generalised approach will not be suitable for these organisations.Wright et al 92008) believes that it is imperative that a unique approach is taken for laboratories while Lopez & Badrick, (2012) & Howes (2019) argue the alternative opinion that most in the field hold, that environmental improvements should be inlign with the 3R concept. Lopez and Badrick discuss the clear conclusions and measures for reduction and reuse of wasted energy, water, containers, solvents, pipette tips and other materials where possible though the concept of recycling materials in laboratories is not as commonly approached. Some of the major suppliers however have 'take back' programs in which they will take single use plastics that have been sterilized and recycle them into plastic lumber used for speedbumps, park benches and decking. (Thielking, 2019).

2.5 CONVENIENCE STRATEGY

Howes (2019) discusses with Martin Radolf, head of environmental health and safety at the Research Institute of Molecular Pathology (IMP) and Institute of Molecular Biotechnology (IMBA), making it more enticing for researchers to use sustainable options using this strategy based on convenience. Researchers can still purchase and refill their boxes of plastic pipette tips from supplies held in the stockroom (stores in Europe). "For plastic pipettes they have to go down to the cellar, to the stores," he explains "The glass pipettes will be placed somewhere nearer the lab," so that the glass alternative that can be appropriately washed at a sterile facility can be used at no expense to the laboratories budget for most purposes making it convenient and accessible to use a sustainable option.

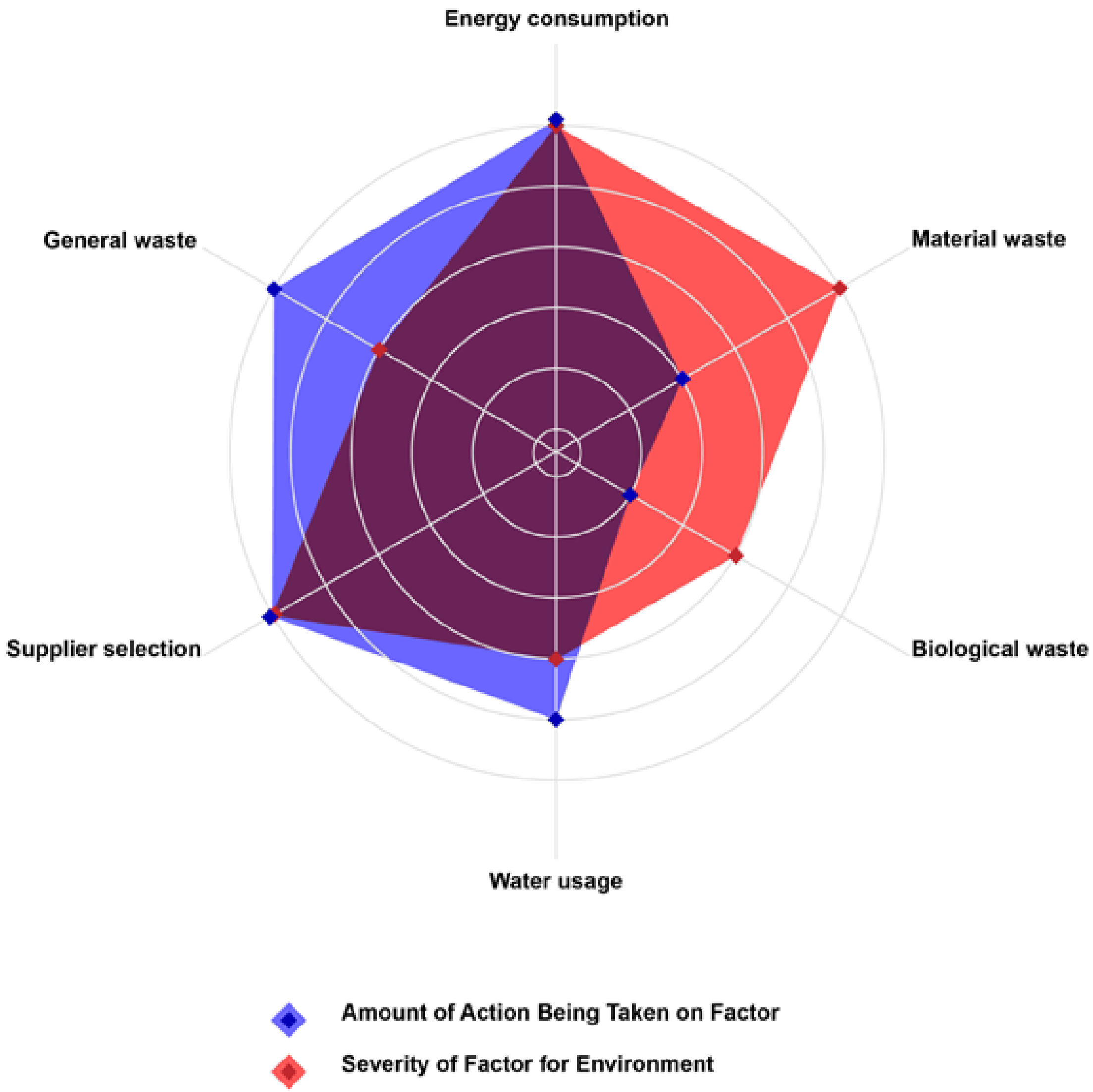

Figure 5: Overview of factor severity and action being taken.
Information sourced from Lopez & Badrick (2012); Ross et al (2019) & Wright et al (2008).

There is an imbalance in how much the industry is addressing unsustainable factors in laboratories. Energy use and general waste, while having a severe impact are some of the most addressed issues, figure 5 shows (based on this author's research) approximately, this imbalance. Action taken on material waste and biological waste using sustainability as a frame of reference shows that, compared to damage to the environment being done by material waste in laboratories, not a lot of solutions exist for laboratories to address this issue.

2.6 MATERIAL WASTE

Manufacturers and organisations have a range of materials that are used in laboratories. PR Newswire (2016) breaks these market segments into glassware and plasticware. Plasticware consisting of pipettes & pipette tips, storage containers, beakers and flasks while glassware consists of the same categories with the addition of petri dishes. Newswire through their market analysis predict pipettes and pipette tips to account for the largest shares of both, glassware and plasticware markets coming into 2020. Each material has their strengths and weaknesses as shown in table 1.

Many researchers prefer plastic due to its durability and flexibility. The combination of affordability and diversity in physical properties has made single-use and other material waste an important and difficult matter to address when it comes to its disposal and end of life (Bhanot, 2015). In 2015 Exeter University teams gathered data to assess their plastic waste in the prior year, concluding that their bioscience department wasted approximately 267 tonnes of plastic in 2014 (Urbina, Watts & Reardon, 2015). To put this in perspective, they further estimate that this number could become 5.5 million tonnes of lab plastic waste in 2014 when considering the 20,500 institutions worldwide. Though this is a rough estimation on their part, the belief that too much plastic and single use material waste is produced is shared with many in the scientific community.

The plastics products used by laboratory supply manufacturers encompass many uses and purposes depending on the need to clean, need to be rigid, transparent, flexible, etc. Different materials are used to optimise their use and often achieve a desired price point. Table 1 shows the materials most commonly used in lab plastics and explains their properties and ability to be recycled.

GLASSWARE		PLASTICWARE	
STRENGTH	WEAKNESS	STRENGTH	WEAKNESS
Chemical Resistance	Chipping	Biosafety	Chemical Leeching
Autoclave Sterilization	Hazardous When Broken	Durability & Impact Resistance	High Environmental Impact
Reusable	Delicate	Manufacturing Costs	Heat Resistance
Acid Resistance		Procurement Costs	
Recyclable		Flexible Manufacturing	
		Low Cost	
		Suitable for Many Purposes	

Table 1: Comparisons of plasticware to glassware.
Information sourced from Newswire (2016) and Molé (2019).

MATERIAL NAME	USE AND DESCRIPTION	HEAT RESISTANCE
High-density polyethylene (HDPE)	Non toxic and non contaminating with high strength. Used for bottles, and large containers. Can hold acids, alkalis, alcohols, hydrocarbons, ketones and oils.	120°C: Not suitable for autoclave.
Low-density polyethylene (LDPE)	More flexible than HDPE and used to make lab trays, dropper bottles and wash bottles.	80°C: Not suitable for autoclave.
Polymethylpentene (PMP or TPX)	A transparent material that is impact resistant. Good resistance to acids, bases, alcohols, mineral oils, and aldehydes though will deform if exposed to oxidizing agents, hydrocarbons and ketones. Used for volumetric flasks, beakers, measuring cylinders and optical windows.	153°C–174°C: Suitable to be repeatedly autoclaved.
Polyethylene terephthalate (PET)	Clear and usable with weak acids, alcohols and aliphatic hydrocarbons and is an excellent gas barrier suitable for use in containing biologicals, media bottles, water bottles, disposable pipettes and face protection shields.	70°C: Not suitable for autoclave.
Polystyrene (PS)	A clear, ridgid material suitable for aqueous solutions, weak acids and bases but is attacked by aromatic and halogenated solvents. Used for plastic test tubes, centrifuge tubes, tube racks, serological pipettes, petri dishes and pipettes. Suitable for Recycling..	90°C: Not suitable for autoclave.
Polycarbonate (PC)	The toughest of all the thermoplastics commonly used in lab equipment. Poor resistance to acids, halogenated hydrocarbons, bases and appreciable resistance towards oil and organic solvents. This is used to make face shields, jars, flasks and bottles.	130°C: Suitable for autoclave.
Polypropylene (PP)	White in colour and best stress-crack resistance of the polyolefins manufactured. Suitable for acids, bases, aldehydes, ketones and aliphatic hydrocarbons and used to manufacture funnels, vacuum flasks, autoclave baskets, jars and trays that require frequent sterilization.	130°C: Suitable for autoclave.
PMMA plastic or acrylic	Low resistance to chemicals and heat, used for transparent bench tops, and safety shields (Ali et al, 2015).	100°C to 130°C: Products are not autoclaved.
'Teflon' fluorocarbon polymers (PTFE, FEP &	High temperature stability and non-adhesive, however sterilization-level doses of gamma irradiation will break the material down. Used for high risk situations in which shatterproof materials are needed and working with aggressive chemicals or extreme temperatures. Included items are magnetic stirrers, stop-cocks, valves, tube connectors, beakers, centrifuge tubes, gas seals.	190°C Suitable for autoclave.
'Teflon' and other Perfluoroalkoxy (PFA)	Similar to PTFE, this is a superhero of materials used in labs. Used for leak-proof Nalgene bottles, beakers, and graduated cylinders.	190°C: Suitable for autoclave.

Table 2: Laboratory plastics and their purposes.
Information sourced from Ali et al, 2015; Bhanot, 2015 and Thermo Fisher Scientific, n.a.

Materials that are highly reusable include glassware such as glass pipette tips, reagent bottles, often this glassware is pyrex or heat tempered (annealed) glass because of the need to handle repeated high temperatures in an autoclave for sterilization. Though the downside of using glass is its brittle nature, having a material that is tough to see and clean up when broken into small shards, can cause cuts easily and in a context in which it frequently has contained a dangerous chemical is very dangerous (Hanlon & Ramilń, 1999 17-20). This is why the prefered material in many cases is plastics. Plastics that have the ability to be reused, as shown in table 2 are PFA, PTFE, PP, PC and PMP as they can be autoclave though there are other sterilization or disinfection methods that can be used to allow a product to be reused such as ethanol, UV sterilization, etc. These have their drawbacks and autoclaving is considered to be one of the most reliable and efficient methods.

PS is a material that can be recycled using common methods, often used to make many common supplies as shown in table 2. Though other materials are recyclable, as shown in table 3, they are only recyclable through specific organisations and special means.

My Green Lab (2020) (See table 3.) discusses recyclability and gives a general guide to labs, indicating which equipment they can recycle however it does very much depend on the plastics these items are made from and at times even the company they are produced by.

PRODUCT	METHOD RECYCLING
Nitrile Gloves	Special waste stream: Recycled by Kimberly-Clark's RightCycle program or Terracycle.
Pipette tip boxes	Through Traditional Recycling methods.
Cardboard	Through Traditional Recycling methods.
Conical tubes	
Centrifuge tubes	
Pipette tips	
Reagent and chemical bottles	Must be thoroughly cleaned depending on the institution's regulations.
Glass bottles	Common Recycling method: Requires no breakages otherwise can be classed as "laboratory sharps"
Hazardous waste	Special waste stream: May be handled through Triumvirat.
Ink and toner cartridges	Through printer manufacturers.
Batteries	Many retailers and suppliers offer battery recycling services.

Table 3: Items that can be recycled according to My Green Lab.
Information sourced from My Green Lab (2019).

2.7 DISPOSAL

Many of these items (conical tubes, reagent and chemical bottles and centrifuge tubes) will depend on the plastic they are manufactured from and will have different recycling capabilities depending on this as shown in Table 2. As table 3 shows some items are only recyclable from specific companies, eg. Kimberly-Clark is one of the very few companies with the capabilities to recycle nitrile gloves. They do this through their RightCycle program in which they have laboratories separate their waste and take some plastics materials and nitrile gloves and garments (including accessories such as hoods, masks, shoe covers and other items) and process it to produce recycled nitrile powder and plastic pellets. (Dunn & Kimberly-Clark, 2016) Requirements for this program are that the items must be free of hazardous materials, biohazards and wet food.

A general approach many clinical labs and hospitals use for contaminated waste or other medical waste is incineration, though many products that have not been exposed to infectious materials can be recycled with appropriate sterilization and care (Lee et al, 2015, 461-470). They are disposed of in the same way due to lack of process initiatives to allow users to recycle.

The incineration of these wastes that contain many of the prior plastics listed as well as PVC at times can release toxic heavy metals such as cadmium, chromium and lead as well as HCl, dioxins, and benzene which are hazardous pollutants that are significantly toxic. (Lee et al, 2015, 461-470)


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2.8 BARRIERS TO SUSTAINABILITY
Many barriers restrict researchers to specific materials and dictate how they are treated. Things that fall into this are: costs of equipment, availability, contamination, biosecurity, hazards and regulations. Occupational health and safety (OHS) is something that must be taken seriously as reintegration of contaminated goods into the supply chain could have severe impacts on people's health. The use of contaminated duodenoscopes (medical devices used in hospitals) has been linked to the spread of superbug outbreaks in the US resulting in a change in manufacture to have disposable end-caps for the devices.(Voelker, 2019; & Drues, 2015).

The physical contamination level comes into play when preventing sustainable efforts such as reusing materials, using materials like glass over some plastics and reducing the amount of plastics or garments used. Sharps such as needles, scalpels, pipettes, and broken glassware must be handled and disposed safely, these pose risk of infection when working with biomatter such as blood and GMOs and require very stringent biosecurity and physical containment restrictions.

There is no general way to dispose of all hazardous chemicals, some will even be altered to become less hazardous compounds. Most will undergo one of several common destruction techniques in order to become safe or be disposed of in gassious into the atmosphere (Lunn & Sansone, 2012, 631-648). At times waste is disposed of through drainage which can contaminate water supplies having a negative environmental impact states Ross et al (2019).

Social barriers are one other issue that can affect sustainability. It can be defined as barriers that are created through people's actions and attitudes towards, policies and sustainable practices or changes. Wright et al (2008) finds through their survey results of laboratory researchers that the major social barriers that affect people are lack of support, lack of information and time constraints.

2.9 GAP
It is clear that there is a wide array of disposal, recycling, reuse and cleaning options available to researchers, manufacturers and waste management organisations. Many laboratories as discussed by Ross et al (2019) & Lopez and Badrick (2012) have not adopted sustainable waste management programs due to costs and due to additional organisational hurdles. By linking these two conclusions it can be seen that an integrated systems based approach, integrating a QMS and EMS including the goal to simplify the process of waste disposal, cleaning and recycling would offer organisations great benefits in reducing their material waste.

3.0 RESEARCH DESIGN

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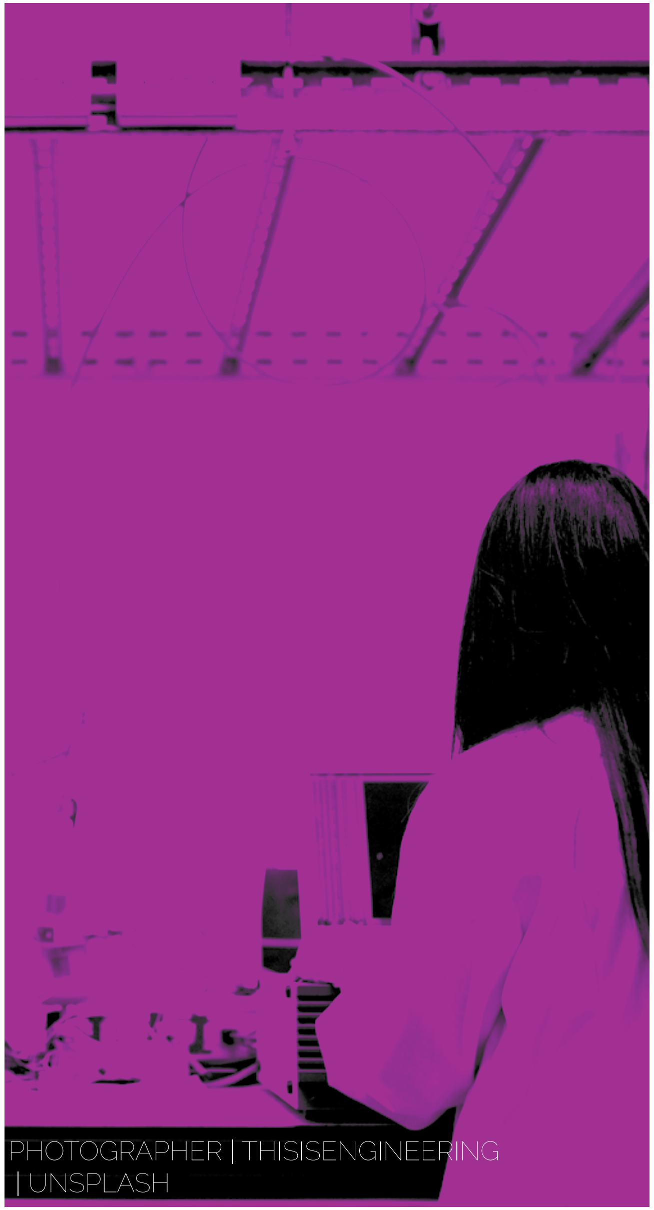


3.1 METHODS

The research aims to gain an in-depth understanding of experiences of researchers and factors involved in decisions when disposing of single-use and disposable laboratory equipment and garments. Based on the understanding gained from this the intent then is to produce a product that can simplify these factors and improve the amount of sustainable choices individuals can make while conducting their work to a high standard.

This study asks the two following questions:

- How do Lab Staff interact with different plastic lab equipment to make it unlikely to be reused or recycled?
- How do sustainable research methods affect quality of research and reaching high standards?

A breakdown of these research questions that isolates the variables that will be focused on can be seen in appendix 4 (12.9).

These questions ensure that quality of research and safety is ensured in the end results and that unsustainable pain points will be addressed in a way that will be inline with the right needs of users considered.

Figure 6 highlights the types of participants that have been aimed for in the sample group. The three groups researched will be the suppliers, researchers and disposal management user groups. This enables a deeper understanding of the full lifecycle of the products, the full range of experiences at play and consider factors from multiple points of view. The multiple user groups will take part in the semi-structured interviews inorder to understand their motivations and receive detailed explanations of their experiences.

Figure 6: Research design diagram.
Author's own (2020).

SURVEY
The survey will be structured using closed questions and scales. The Research objective is to answer the research questions described in the methodology and to build on and validate the information gathered in the literature review. The survey will be deployed, results will be monitored and one round of reminders will be sent. Then the data will be analyzed and findings will be recorded.

SEMI-STRUCTURED INTERVIEWS
Inorder to gain this in-depth understanding it was determined that a set of semi-structured interviews would allow this research to explore more valuable experimental data from participants. Whiting (2008) describes semi-structured, in-depth interviews as using “open, direct, verbal questions” “to elicit detailed narratives and stories”. The challenge in this method is maintaining control over the interview while respecting the role of the participant, so they do not feel like they are just being waited on to produce the next piece of data, Whiting further explains.

TRIANGULATION
To ensure that data gathered is reliable and valid, the triangulation method was employed. According to the Flick (2002) definitions of triangulations two forms of the strategy will be used. Methodological triangulation is used to gather data with two or more methods of research, in this case surveys and semi-structured interviews. This is done to benefit from the strengths from each method and “maximise the validity of field efforts”. The second form is triangulation of data, the process of gathering data from multiple sources. This can be people which will be occurring though, more importantly the data sources will be from different parts of the product life cycles (suppliers, researchers and disposal management). Figure 7 highlights this methodology.

LIMITATIONS
This study faces some limitations in gathering first hand data. Due to privacy and security of research being undertaken in some laboratories it is likely not all photos or video footage will be able to be taken in order to respect the security of the organisation. As of the date this research is being undertaken there are national measures in place due to the COVID 19 outbreak and the Australian health regulatory commission has social distancing regulations and this research will be conducted with this in practice. The sample group investigated may not be as diverse as desired due to limited participants, this must be taken into consideration when analysing the findings.

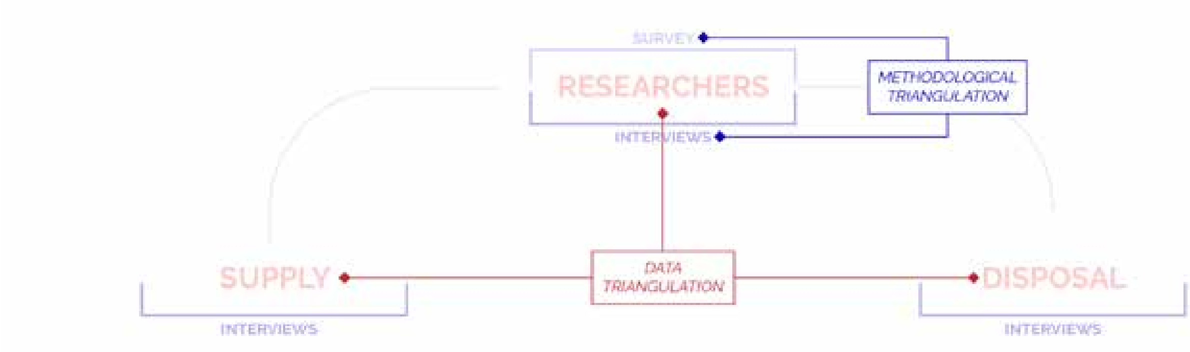
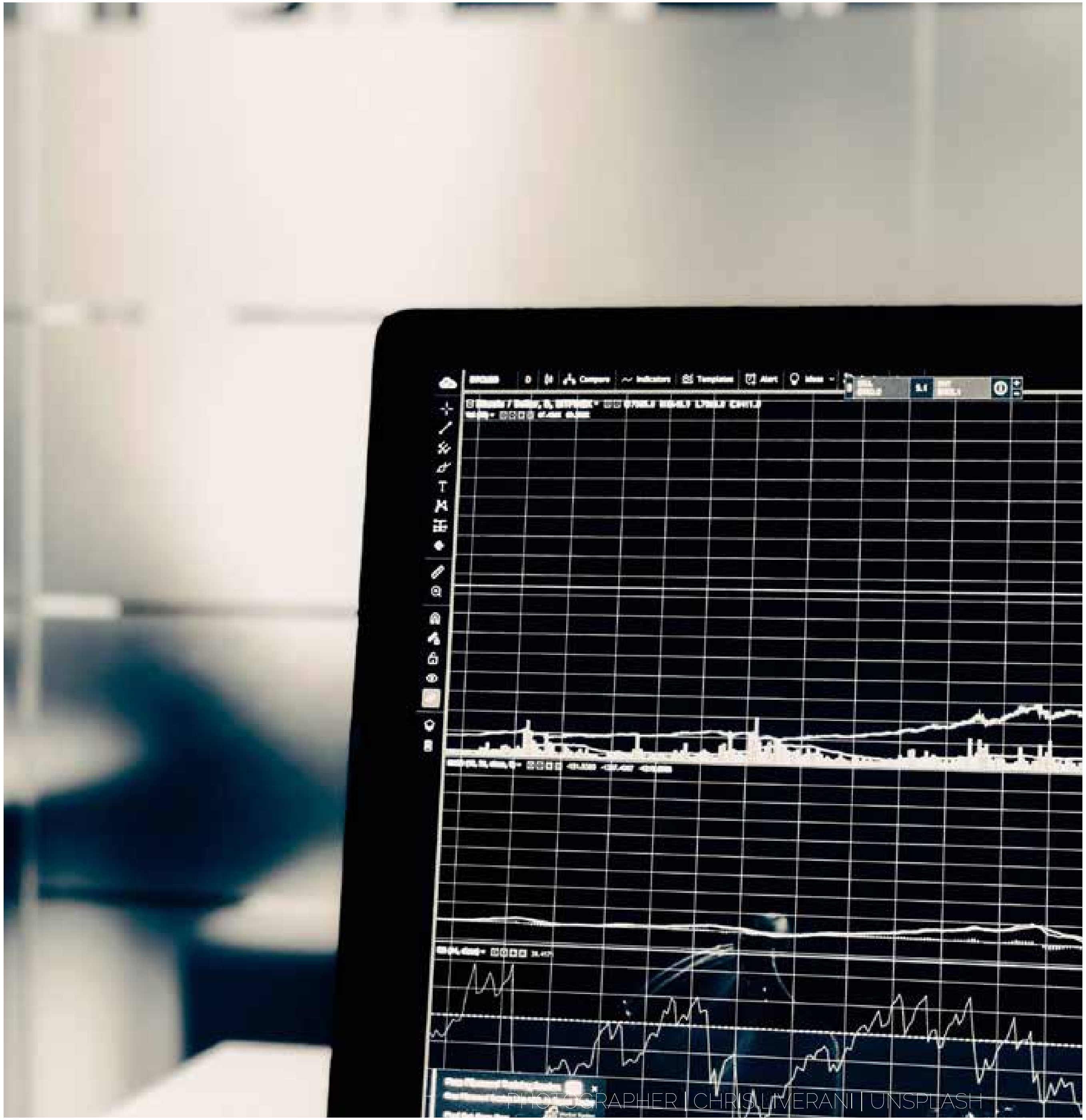


Figure 7: Research design triangulation diagram.
Author’s own (2020).

4.0 ONLINE SURVEY



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The survey was launched as a surface level tool to try and gather information from the larger laboratory user group and establish general understanding of the topic. As the study by Wright et al (2008) denotes, time constraints were an important factor for laboratory scientists this is why the survey was limited to 15 questions (including a request for follow up interviews). The survey covered equipment wasted, barriers to sustainability and users' beliefs and habits regarding sustainable practices in laboratories.

4.1 PARTICIPANTS

Online survey participants were approached through online forums including university social groups, online researcher communities and email. The web-link to the surveys were attached to a flyer and to emails sent out for people to independently follow and fill out. Some respondents are academics form a global online community, these respondents were sent a separate link to a duplicate survey to keep results separated. Survey participants were either in charge of a part of a laboratory or had personal experience working in and dealing with waste in laboratories. The study resulted in 22 usable participants out of a total of 26 respondents. These participants were primarily young adults in as figure 8 shows and figure 9 shows, had experience in a range laboratory positions though around 30 percent of participants were university students.

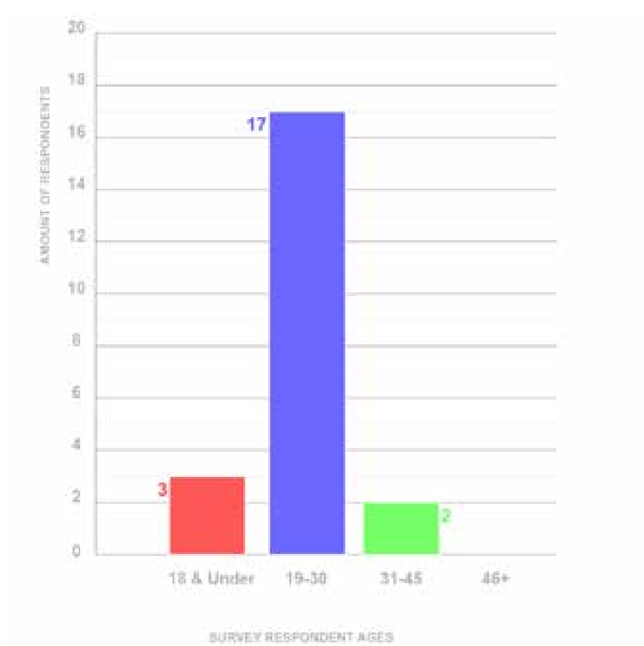


Figure 8: Respondent Age Groups
Author's own (2020).

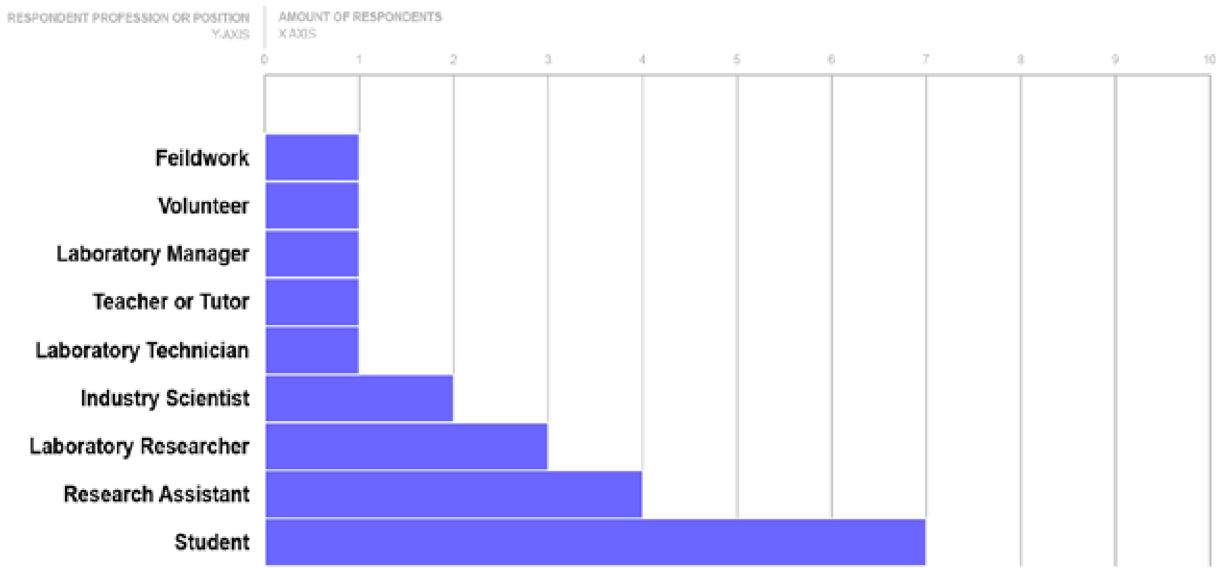


Figure 9: Respondent professions and positions graph.
Author's own (2020).

4.2 ANALYSIS METHOD

The questions were a mixture of closed and open ended questions, taking a qualitative and quantitative approach to data sourcing. Some questions were designed as follow up questions to understand the data from a different angle. As shown below, the analysis breaks down the answers into 4 categories that can be used to understand and connect the data to the research questions.

- Equipment that is disposed of
- Barriers to sustainability
- Waste methods

Some open questions were grouped to into correlating 'likeness' eg. answers that indicated centrifuge tubes, eppendorfs, sample tubes and suction tubes were grouped into the class 'tubes'. This was done to make the data simpler and achieve the goal of a general understanding of the topic.

4.3 EQUIPMENT

The first topic that will be discussed is the equipment that is being used and disposed of. This will discuss which equipment is being disposed of, quantities and details about specific disposables or consumables that was supplied in the survey.

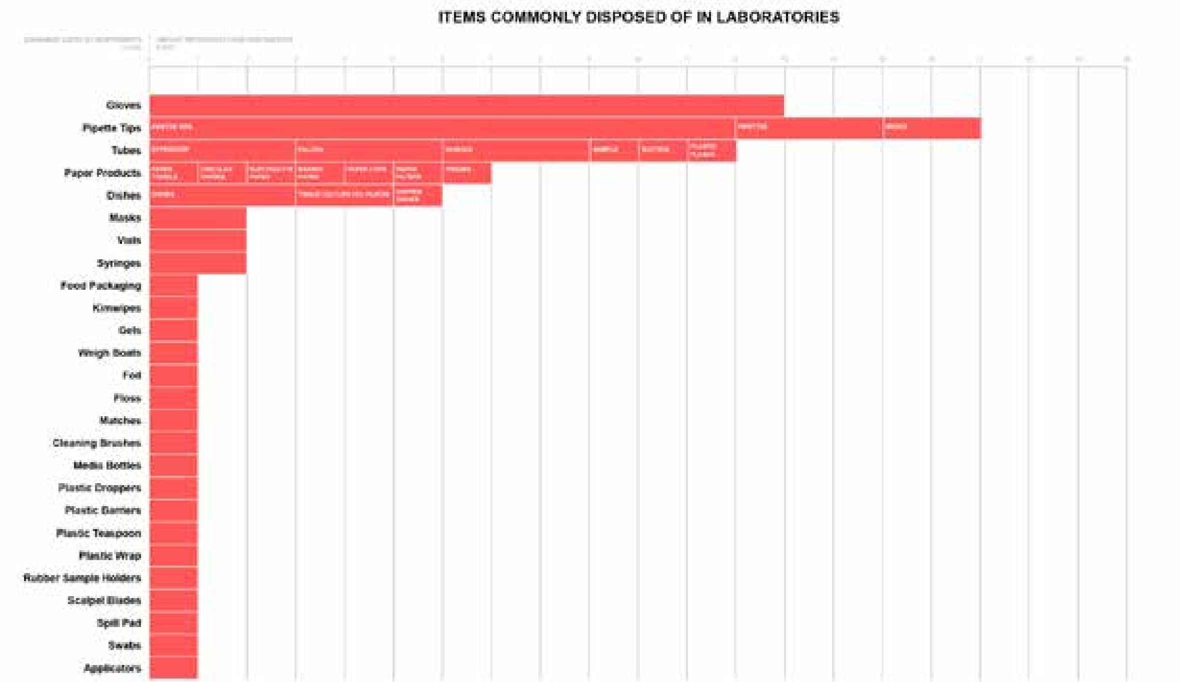


Figure 10: Open answers - "What disposable equipment do you commonly use?"
Author's own (2020).

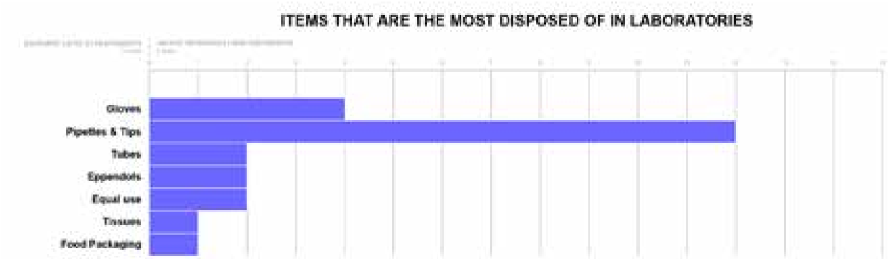


Figure 11: Open answers - "Which of these are used the most?"
Author's own (2020).

Figure 10 shows the range of materials recorded when asking participants which disposable equipment they often use. It shows gloves as the most wide-spread individual item and the pipettes & tips grouping being mentioned the most times. This data indicates that the items most commonly disposed of are gloves, pipette tips, tubes, paper products and tissue culture dishes (TC dishes). The third value in this set shows that tubes are segmented into several individual products, indicating that a wide range of these products are commonly used.

Figure 11: “Which of these are used the most?” Though when these values are compared to figure 11, it can be seen that the products disposed of at the highest volume are pipettes & tips. Contrary to this evidence however, many who did indicate gloves were a large contributor to their laboratory waste, also mentioned frequent disposal, emphasising that it was essential or recommended. From this, a reasonable assumption to make is that though gloves are not the highest disposed of item for laboratory users in this survey, those who do dispose of gloves the most do it at a very high volume. This is supported by figure 12, showing though a minority of respondents use over 5 gloves in an average day, the users that are in this minority use significantly higher quantities.

Averaging the users above 5 and those below and including (rounding ranges to the highest whole and making variable numbers whole numbers) shows that on average the eight users in the upper end of glove usage tend to use 6.8 times the amount of the bottom 16 users.

Regarding equipment, the data has shown that gloves are the items that are the most common contributors to laboratory waste, however, pipettes and tips are a larger contributor to laboratory waste for most researchers in the scope of this study. This may not be the case in all laboratories and is subject to a high degree of variance depending on the industry a laboratory user works in. Inorder to ascertain a clearer picture of equipment involved in this a larger sample size with a varied range of industries would need to be surveyed.

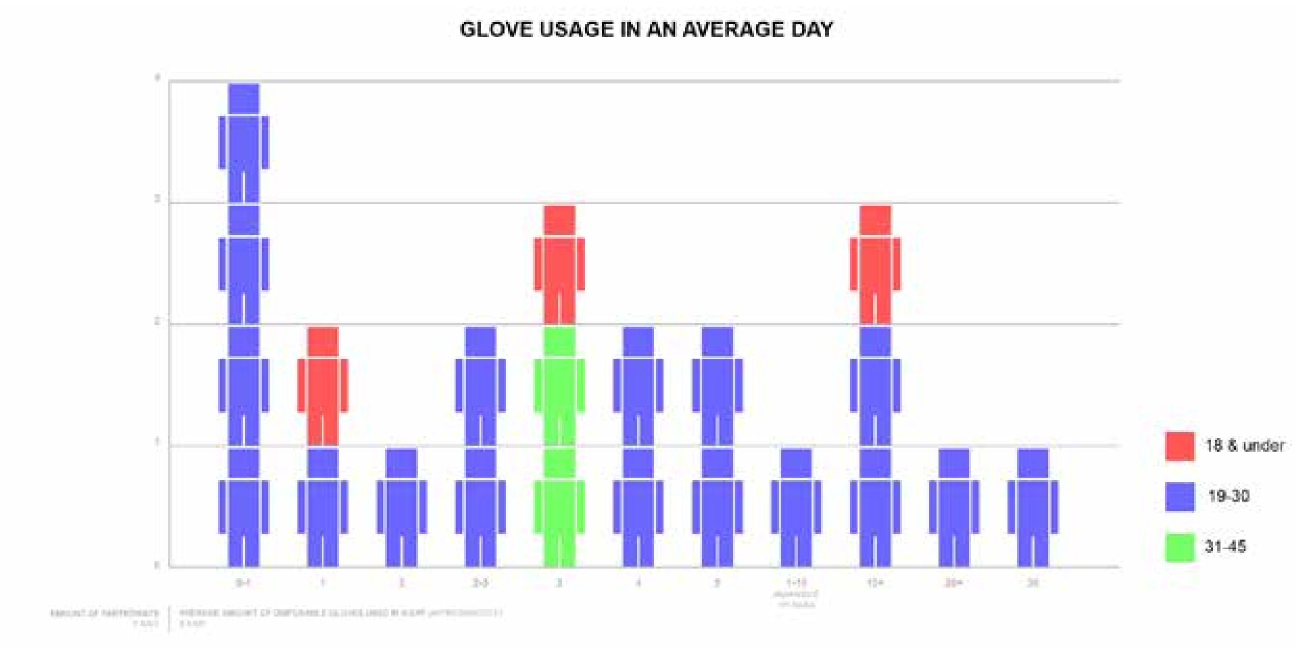


Figure 12: “How many pairs of gloves do you use on an average day?”
Author’s own (2020).

4.4 BARRIERS TO SUSTAINABILITY

The survey posed questions about barriers to sustainability in two formats, open ended questions and as closed questions. This is to understand the information from two angles and evaluate/validate information gathered in the literature review segment. Important findings

Figure 13.1 shows the results when asked:

> *“Based on your own experience, which of the following factors contribute the most to the disposal of plastic lab waste?”*

and given factors to choose from that were revealed through the literature review. It is interesting that this reveals a primary factor being that the product is not designed to be reused as this opens a gap to design of products that fulfill the same needs while being designed for reuse. This gap is analysed against the results of the interviews and is not necessarily inline with what researchers further talk about as the main barriers.

Figure 13.2 shows the results from an open ended question regarding barriers. It must be noted the question

> *“In relation to your previous answer (do you believe your research could be conducted in a more sustainable manner?) what are the main barriers?”*

Participants interpreted in one of two ways, some interpreted the question as *“what are the issues for sustainability in laboratories?”* and others interpreted it as *“what are the barriers that prevent researchers from acting sustainably?”* This question was worded poorly resulting in a split of data gathered, Inorder to understand the barriers, the latter will be analysed and the prior will be disregarded in this topic. As figure 13.2 shows the top 3 barriers that were indicated by researchers were “need to be sterile”, “time constraints” and “cross contamination” this is inline with results from figure 13.1, though time constraints has been introduced as a barrier. This must be taken into consideration in later steps of the study.

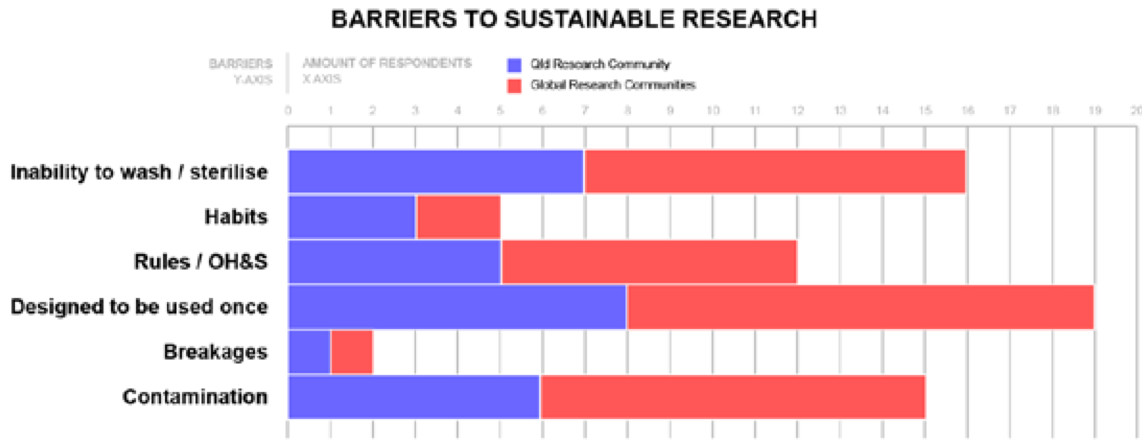


Figure 13.1: Closed answers “What are the major barriers to sustainability in your lab?”
Author’s own (2020).

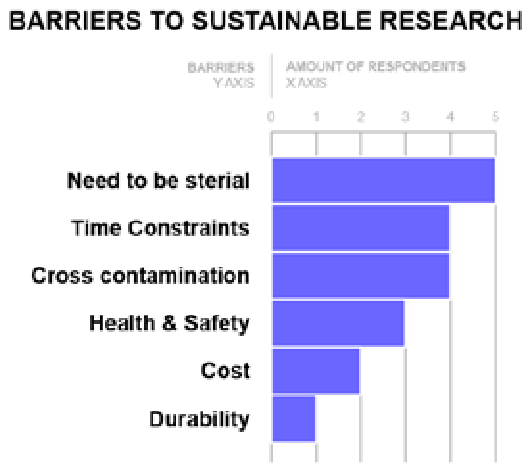


Figure 13.2: Open answers “What are the major barriers to sustainability in your lab?”
Author’s own (2020).

4.5 METHODS OF DISPOSAL

The next topic is the waste disposal methods and regulations followed in laboratories. This is highly dependent on the PC (and other regulatory standards) level of the laboratory and depends on the materials being worked on as the literature review discusses. A general distinction is clearly made between how independent researchers (such as PhD students and postdoctoral researchers) and students, learning in laboratories dispose of consumable laboratory equipment through the findings of this study. More details about this however, are revealed in the interview section.

The results regarding recycling in laboratories and reuse of equipment is interesting as it is consistent with findings in the literature review. Many laboratories have few/no initiatives in place to enable recycling of product as figure 14 shows, though it is interesting that users sometimes do as the literature review indicated this did not occur as often as the respondent results show.

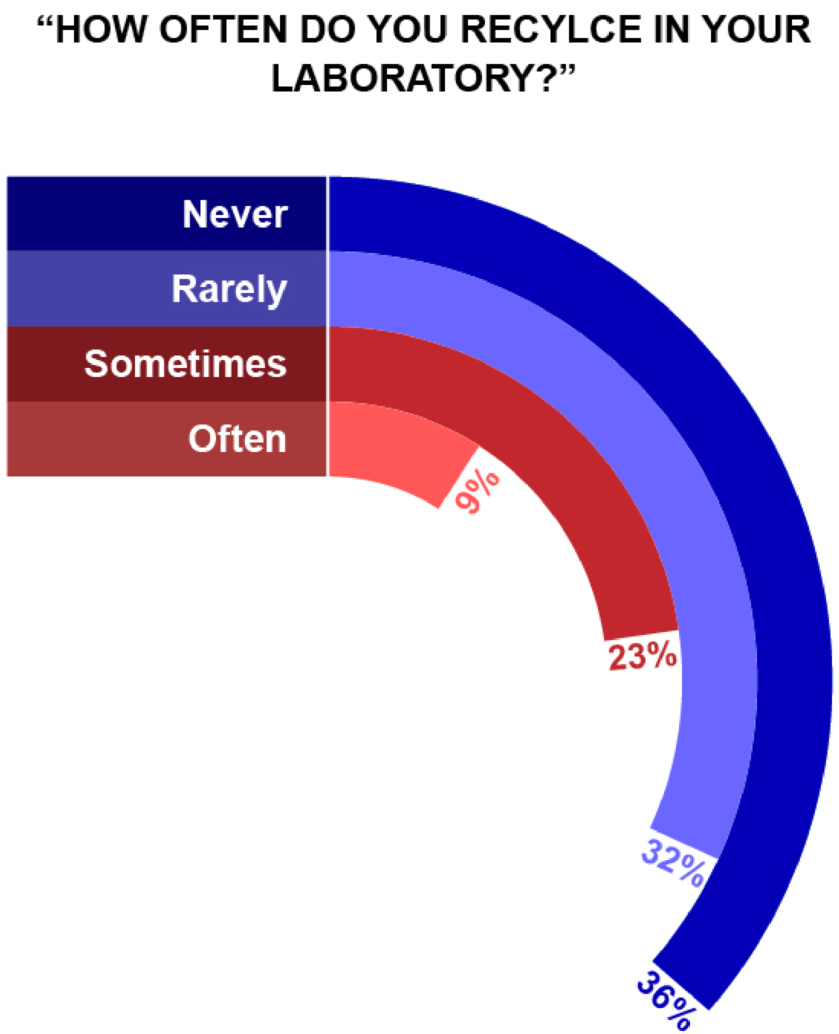


Figure 14: "How often do you recycle plastic in you lab?"
Author's own (2020).

Figure 15 shows the amount of waste categories that respondents have in their laboratories. This ranges from 1, which could presumably be general or contaminated waste to 8 which indicates a more complex system of waste disposal for varying risks of by-products.

The results from the survey show a mean value of 3.6 kinds of waste disposal methods for most laboratory users. The data shows that industry users are more likely to work in complex laboratories that have a wider variety of waste categories. While university students and research assistants are more likely to have a smaller variety.

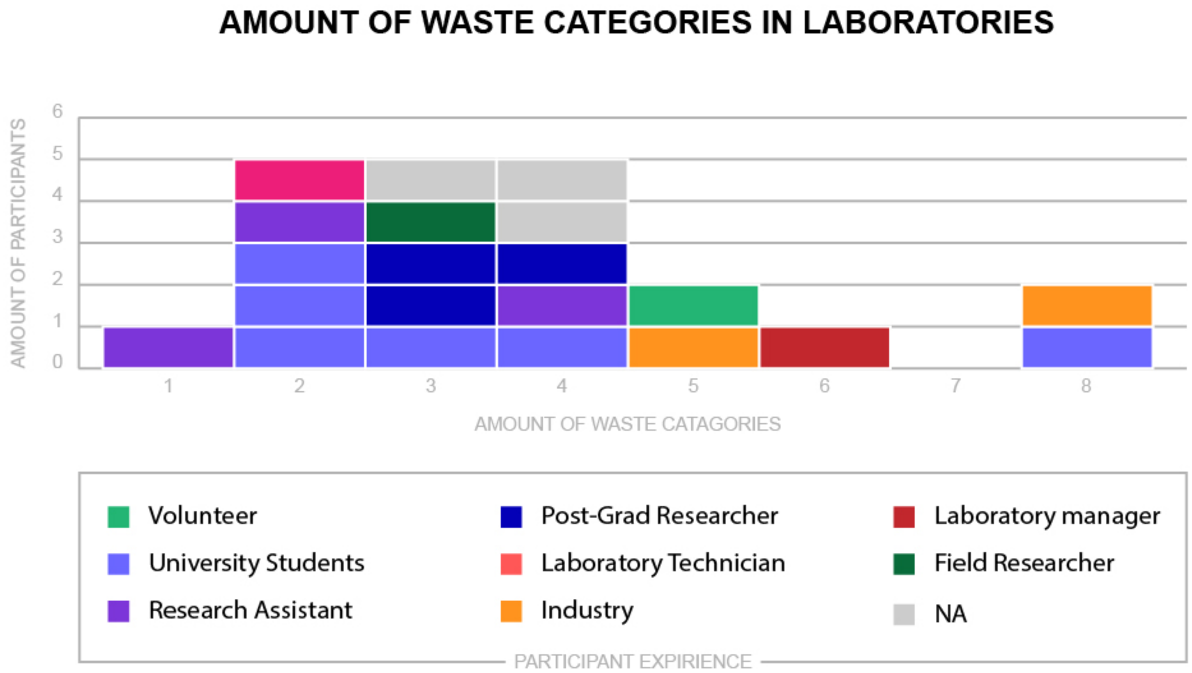


Figure 15: Cross tabulation - Amount of waste categories in laboratories against user positions.
Author's own (2020).

5.0 SEMISTRUCTURED INTERVIEWS

PHOTOGRAPHER | CHRIS MONTGOMERY | UNSPLASH

The semi-structured interviews were conducted over Zoom and recorded. An example of the interview questions can be found in Appendix 2 (12.2). Questions were designed to develop deeper insight and understanding into the roles of participants in laboratories and the factors that surround disposable laboratory equipment. Participants of the survey would further participate as interviewees as well as manufacturing professionals and individuals with laboratory supply expertise, to supply richer data that could be used to understand the details of the topic and result in more focused issues. The participant breakdown is listed below and shown in table 4 and table 5.

- 7 interview participants in total
- 6 Laboratory users
- 1 Equipment manufacturer

These participants outlined below are primarily academics from Australian universities contacted through personal networks and other university connections.

5.1 LABORATORY USERS

PARTICIPANT	AGE	GENDER	DISCIPLINE	POSITION
Participant 1	19-30	F	Environmental sciences	Student
Participant 7	19-30	F	Chemistry	Student
Participant 2	19-30	F	Microbiology	Researcher
Participant 6	19-30	F	Microbiology, chromatography and animal physiology.	Researcher
Participant 5	19-30	M	Biochemistry and molecular biology	Post PhD Researcher
Participant 3	41-45	F	Biosciences	Laboratory Manager

Table 4: Laboratory user demographics
Authors own, 2020

5.2 EQUIPMENT MANUFACTURING INDUSTRY

PARTICIPANT	AGE	GENDER	DISCIPLINE	POSITION
Participant 4	19-30	M	Lead Design and marketing	Professional Industrial Designer

Table 5: Manufacturing participant demographics
Authors own, 2020

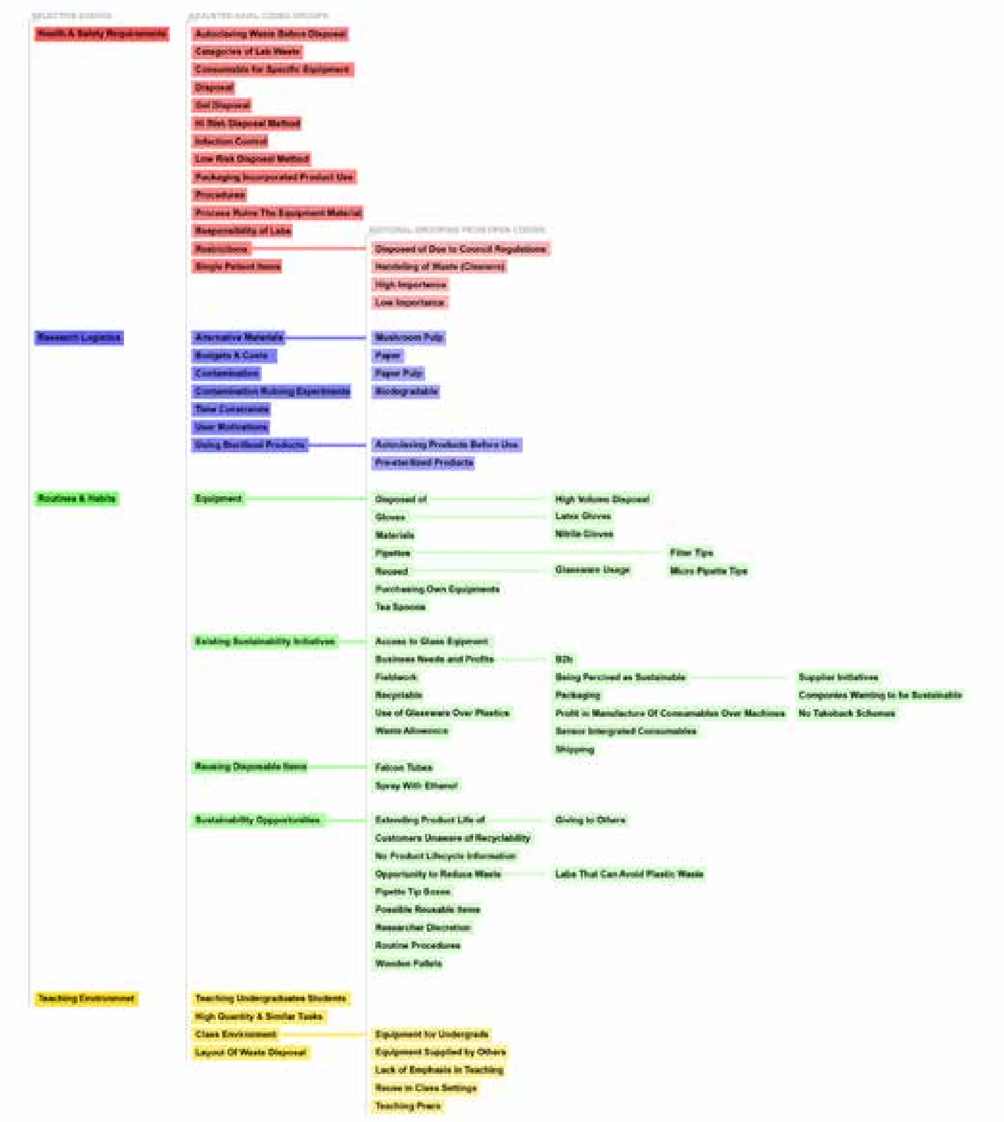
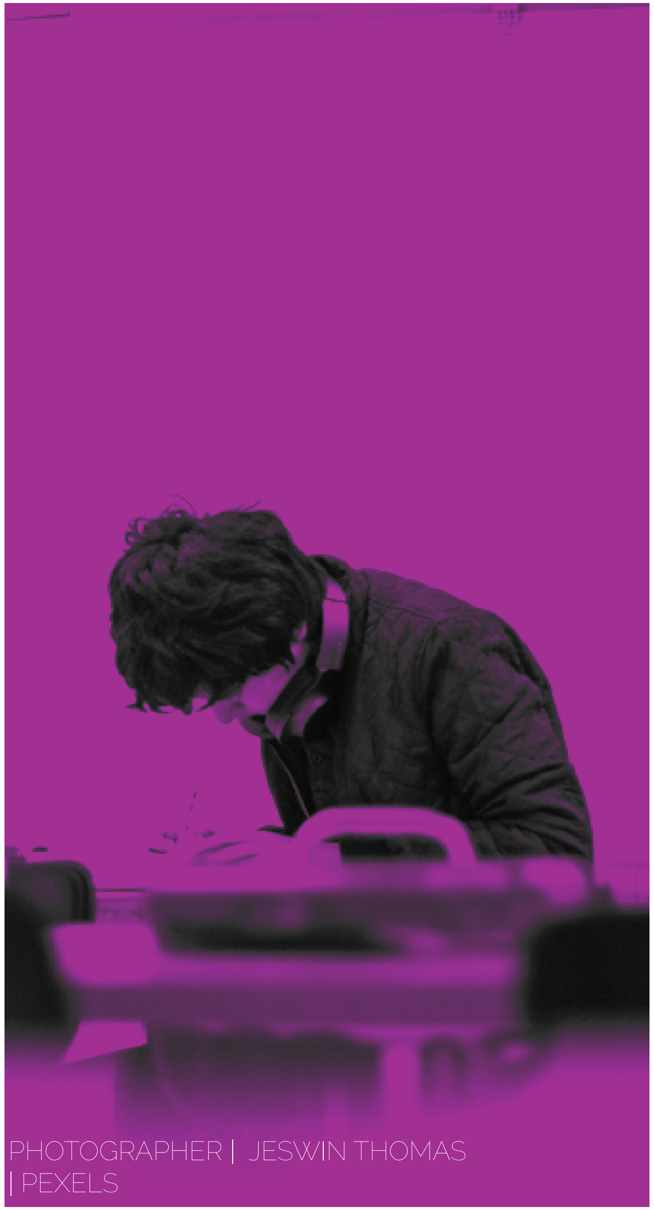


Figure 16: Final coded structure from selective coding stage.
Author's own (2020) coding preformed in NVivo 12.

5.3 ANALYSIS METHOD

Inorder to analyse the qualitative data supplied in the interview process and probe the data effectively using a legitimate form of inquiry, a grounded theory approach was employed to analyse the transcripts. This was chosen due to the widespread and successful application of grounded theory in social sciences. As Charmaz (2010) explains, this approach uses three phases to code the data; open coding, axial coding and selective coding. Open coding was used while reading through transcriptions of all interviews to break the transcripted interviews of laboratory users down into 61 separate codes and of the manufacturing industry interviewee into 20 codes, following this, the two groups were combined and axial coding was applied to the data sets to find relationships between codes, resulting in 10 groups. These groups were grouped tightly, due to this not all of them were refined further when proceeding to selective coding(though a theme may be drawn from the grouping). The final phase of analysis was selective coding in which the axial coded groups were combined and changed into 4 core themes.

Figure 16 shows the breakdown of the selective coding stage though an example of a coded transcript can be found in appendix 2 (12.3) with a open coding hierarchy chart for open and axial coding in appendix 2 (12.4) and individual nodes can be seen in appendix 2 (12.5).



PHOTOGRAPHER | JESWIN THOMAS | PEXELS

5.4 INTERVIEW FINDINGS

The study initially aimed to discover how laboratory users interact with different plastic lab equipment to make it unlikely to be reused or recycled and how sustainable research methods affect quality of research. Through the analysis of interview transcripts it was found that discussions from participants could be allocated to the key themes: teaching environments, health and safety, routines and habits and, research logistics.

5.5 TEACHING ENVIRONMENTS

University teaching environments are large contributors to the laboratory plastics wastestream, this topic was not specifically addressed in the literature review though has been described by students, academics and teaching staff who took part in the interviews.

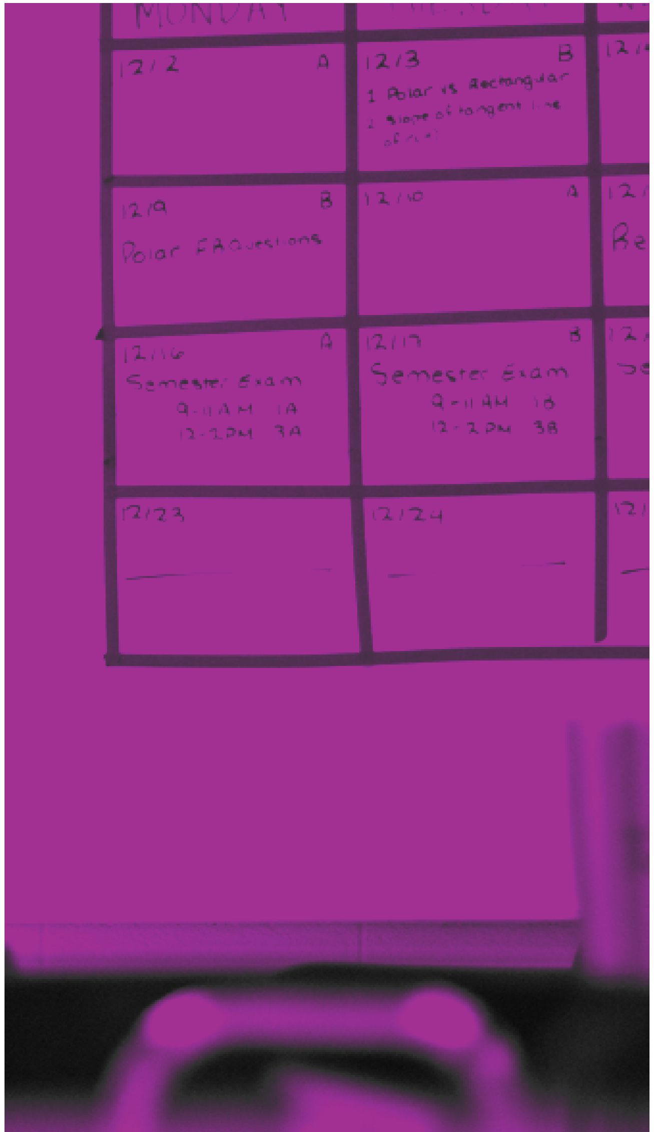
A key issue is the lack of focus in building sustainable habits in undergraduate classes, this means moving forward the practices that users take into the other laboratories that they perform work with do not alway hold sustainability as a priority as interviewees discuss when recounting their prior learning.

It was found that a likely contributor to this problem is the way classes supply students with equipment to learn with. Multiple student participants state they may be required to supply some equipment such as lab coats and protective glasses though most is supplied to them and they are not given any other options that take sustainability into consideration.

A teaching participant discusses that it is of benefit to the coordinators and university to prepare a practical laboratory class (practical) with disposable plastics as it is cheaper and there is a lower risk of breakage etc. Due to the large quantities of students and the similarity of tasks, practicals are able to save money and time by using high quantities of disposable equipment. A benefit of this, as participant 5 discusses, is this makes cleaning up more convenient and ensures the quantity needed is supplied and sterile/undamaged. Participant 1, (a previous undergraduate student) discusses their experience in laboratory practicals.

"we don't all have to go out and buy our own stuff and I guess like, they have the funding to buy the latex gloves and everything in the plastic stuff"

Participant 1



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Even if the student would prefer a sustainable option they are not provided any opportunity to select from alternative equipment or methods, as participant 8, a chemistry student states.

"But I feel like that's because we are undergrads," " We don't need the same options as someone doing a research program. Ah, yeah. It's basically 'Use this, you don't have options.'"
Participant 8

Due to the way equipment is supplied, participants with experience teaching in laboratories agree that, as participant 5 states, "classwork is actually a lot more wasteful than most labs" participant 5 believes that this is because funding from classes come from the university and coordinators are able to supply students with equipment more freely. This is opposed to post-doctoral or other researchers who have to be careful with their research budget as it is limited and more difficult to manage. Using microscope slides as an example of the difference between equipment use for researchers and classes communicates this

"In a lab, those are very often sterilized and reused. Whereas in a student's class, like every time I've ever worked with them, we would just be opening brand new boxes of slides and discarding them at the end of the practice."
Participant 6

Cleaning, storing and setting them up for the next class to work with would prove to be too time consuming and the additional effort is not worthwhile for teaching staff because the budget allows for new equipment each class.

5.6 HEALTH AND SAFETY

A core reason behind the purpose of single-use equipment is the need to preserve health and safety when working with substances that could be dangerous to researchers and the public. This is a common barrier to reuse and recycle sustainable practices that are discussed in the literature review.

Interviewees discuss the types of waste disposal systems in place that act as a way to best contain equipment that could be deemed a hazard. These include, Sharps, biohazardous, biological waste, flammable, radioactive, infectious, toxic, and so on. These categories vary between each respondent and some may have more than others, as figure 15 also shows.
All interviewees in the laboratory user group shared the waste disposal categories, general waste, sharps disposal and either contaminated and/or biohazardous waste disposal. The only recyclable waste disposal offered was in offices that were connected to labs. Multiple participants discuss the processes involved in appropriately disposing of waste, including additional steps such as autoclaving waste prior to disposal and disposing of harmful waste in containers that prevented access or were made from specific materials.

It is clear by discussions with users that theres are followed to the discretion of each laboratory user or teaching staff member and items that are considered a lower risk offer areas of opportunity for sustainability initiatives. Participant 3, a laboratory manager brings up possible opportunities to reduce waste of plastics when discussing low risk and high risk waste.

"some materials that we consider to be high risk, and we want to pass sterilize them on site and a facility that we have within the building and then they go to clinical waste"
Participant 3

These materials are strictly regulated however items such as pipette tip boxes and other items that pose no risk from a health and safety point can be collected and recycled, however it is a matter of storage and transport to ensure this can happen.

One approach that could be taken would be to further divide waste categories to include products that are low risk and are recyclable. This kind of waste, as participants agree is more often than not all dispose of in contaminated waste streams, which in itself may contaminate products that are unlikely to be contaminated. A use case in which this is approached is discussed with the manufacturing participant, where participant 4 discusses their company's approach to recyclable products. They are technically recyclable as products mentioned are made from polypropylene. Stating other recyclable products in the market are made from polypropylene and "councils they are in contact with" "all recycle this type of plastic."

In laboratories this may not be enough to ensure that products are recycled. This is viable however due to the "Single patient" nature of the items as opposed to "single-use". These products are often supplied to clinical laboratories, in which a patient will use these products to use a machine or piece of equipment as a means of infection control, often taking them home to use equipment before disposing of the infection control product themselves. Items that are single patient items are inherently reusable discusses participant 4 "So it's reusable. It's just you can't just wash it and give it to another person"

5.7 ROUTINES AND HABITS

Routines and habits of laboratory users make a large impact on the everyday sustainability of their work, however this also presents the largest area of opportunity to improve sustainability in laboratories. Participant 6 believes through a conscious effort to improve individual sustainable practices in work he has been able to effectively reduce his plastic waste “minimized my use of plastic by about I would say 50%, which is great. I really feel good about this.”

This participant made the most active strides towards reducing waste, making their interview a valuable case study. The key points that they highlight in their experiences were:

- Practicing sustainable routines for daily or repetitive tasks
- Cleaning pipette tips when working with low risk materials (gels in case discussed)
- In-depth knowledge about the matter one works with
- This includes knowing what can risk being contaminated with other materials.
- User discretion
- Appropriate senior mentoring

Participant 6 also speaks about the shortcomings of sustainable practices in the scientific education system.

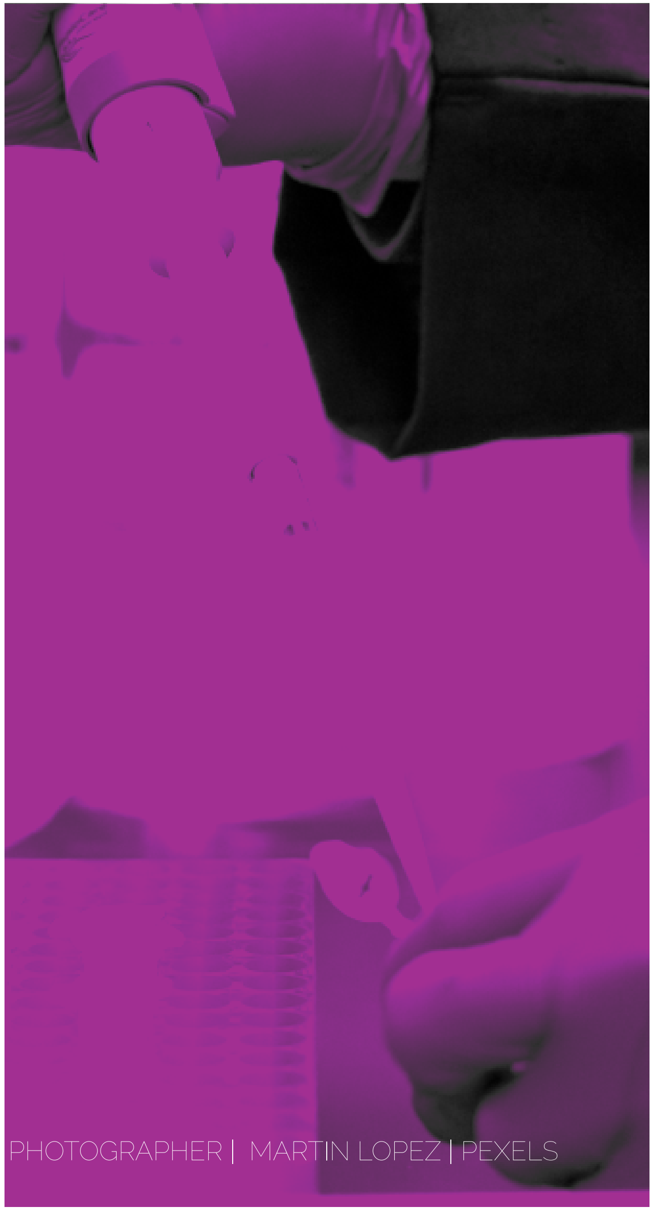
“if you ask for classroom teaching, no, they don’t teach you it’s, it’s only when you have a very enthusiastic senior is like, Oh, I have done it this way. I think it makes a difference. You can do it up to you. But there is no such formal training process where they tell you no, don’t use plastic.”

Participant 6

In this statement they also bring up the importance of a senior-junior mentorship relationship in their experiences.

Almost all other researchers in the study feel strongly that they would want the ability to conduct their work in a more sustainable way, with disposable equipment being the major source of their observed waste.

All laboratory users agreed that the major barrier preventing this is the risk of contamination that researchers are often wary of and, at times, causes anxiety, resulting in excessive waste. The participant with the highest glove usage indicated that their usage was higher than others because they felt strongly that their gloves should be changed each time they were exposed to any contaminant. While other participants stated they exchanged gloves according to specific procedures, for example; when working between infectious and non-infectious animals they would dispose of gloves and work with new equipment though when pipetting simple reagents they would use one pair. There is an opportunity in these varied glove usage to reduce the amount of glove waste by introducing new ways to clean gloves and keep them fresh or sterile during use between specific tasks.



Study logistics refers to the logistics in planning research studies and classes that many organisers and lab users need to consider when planning their experiments. These considerations include budget, time, risks and other factors of value that vary depending on the research.

"So you do try and reuse wherever you can. But that's really limited in what we can use. Like, for example, just a tube we could only probably reuse twice if we don't deal with anything dangerous or hazardous. Hmm, other than that, pretty much everything gets incinerated."
Participant 2

Four other participants expressed the importance of preserving budget and the theme of frugality encouraging re-use of disposable equipment emerged in the axial coding stage.
Though frugality encourages re-use it can also persuade inventory management or researchers to purchase low strength plastics over more sustainable options like glass because it is more affordable in the short term.

"It's convenient to use plastics, it's cheap"
Participant 6

Furthermore, this category also encompases the tangible and intangible value in a researcher's work. Firsthand accounts in interviews shows that flaws in experiments may result in having to reconduct the experiment and can waste a researcher's valuable time, efforts and money. This is why many researchers will opt for a pre-sterilised disposable container or piece of equipment at various stages of their work and replace the used disposable with new one frequently, reducing the risk of this happening.

Some tasks that have less risk, lower cost/time expenditure and may not affect things if small amounts of contaminants are introduced, can afford to use more sustainable equipment that has the ability to be cleaned and reused, options that will ensure a high accuracy and low risk of contamination must always be present and used where needed.

6.0 DISCUSSION

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Two key research questions were derived that would reveal a deeper understanding.

"How do lab staff interact with different plastic lab equipment to make it unlikely to be reused or recycled?"

How do sustainable research methods affect quality of research and reaching a high standard of results?

These two questions were taken from the identification of gaps in research that indicated opportunities surrounding recycling and extending the product life of disposable equipment. The findings in firsthand research lead to the presumption that this could be most effective for waste that presented a low or no risk of contamination.

The following topics were identified as key areas or opportunities that could offer this thesis a means to improving sustainable approaches to laboratory research.

6.1 SYSTEMATIC APPROACH INTEGRATED WITH A QMS

The Quality management system in place in laboratories already provides an excellent platform to expand into an integrated quality and sustainable management system supplying a tested (Ross et al (2019) & Lopez and Badrick (2012)) approach to introduce sustainable initiatives into the laboratory. Though through the insight supplied through interviews, it is clear this must be conducted with financial incentives and must not overcomplicate researcher's works.

Targeted areas when doing this may include waste management procedures and systems, auditing use of equipment and chemicals, procedures and systems for extending life of laboratory equipment and encouraging frugality in researchers use of equipment among other possible areas.

6.2 Teaching laboratories

The insight into contexts that teach students and inexperienced researchers such as laboratory practicals shows that current practices are more wasteful than typical laboratory use. Interview accounts also specify that a foundational issue in independent researchers' poor laboratory waste habits begin in the foundational stage of learning to perform laboratory practical work. Leading to the conclusion that inorder to improve sustainability in laboratories strategies to show students the importance of sustainable practices in lab research could lead to a significant impact on the future wastefulness of researchers and professionals.

Solutions targeting this area must take into consideration:
The time constraints teaching staff are under as any solution that requires a higher amount of prep or clean up time than current cleanup procedures is likely to be rejected.

The complexity of procedures must be approachable and be visible to students. Acquiring materials must not prevent a hurdle as specific and high quantities will be needed depending on the items. This may be overcome simply by creating a closed loop, in which the products are not disposed of at the end of classes and are cleaned appropriately for the next group or class.
Cost must not be too much higher than costs of supplying the products new. Though additional environmental value is added through teaching sustainable practices, it has been indicated heavily that costs are a significant barrier for many laboratory users and is highly likely to play a significant factor when influencing decision making of a given university, school or teacher. Higher individual item quantities than traditional lab contexts. Equipment is likely to be needed and sterilized at high quantities of similar or the same products.

6.3 HEALTH & SAFETY

Findings in the literature review lead to the conclusion that further research was needed into the likelihood or recycling and further reuse of products to extend their use-life. Through the first hand research conducted (semi-structured interviews and online surveys) several barriers and opportunities were shown that reinforces the likelihood of reuse of disposable equipment or equipment designed for reuse in specific circumstances and to individual researcher discussion. Health and safety procedures however, indicate that it is unlikely recycling will be a viable option for the majority of equipment-use contexts. The exception being items that are no or low risk of jeopardizing health and safety; for example pipette tip boxes and styrofoam “cooler boxes”.

6.4 ROUTINES AND HABITS

This area of opportunity focuses on making changes to the behaviors of users that may be unjustified or producing excessive waste. Findings have indicated that these behaviors exist in use of pipette tips, gloves, mixing containers such as tubes, eppendorfs, dappen dishes etc.

A theme that is interesting is the motivations of laboratory users, with the majority of users very aware that their waste is higher than they believe it should be. The results show this, with the survey indicating over 75% of participants agreeing that their research could be conducted in a more sustainable manner (Shown in figure 17) and from the accounts of interviewees indicating their frustration with plastic waste in laboratories. Information in the literature review shows that professionals do not think sustainable research is inferior research, which respondents in the survey further reinforce (see appendix 3 (12.7 and 12.7) for survey results summary). With these two points taken into consideration it seems probable that, given an option that is more sustainable and will not compromise quality, researchers will be motivated to use said option.

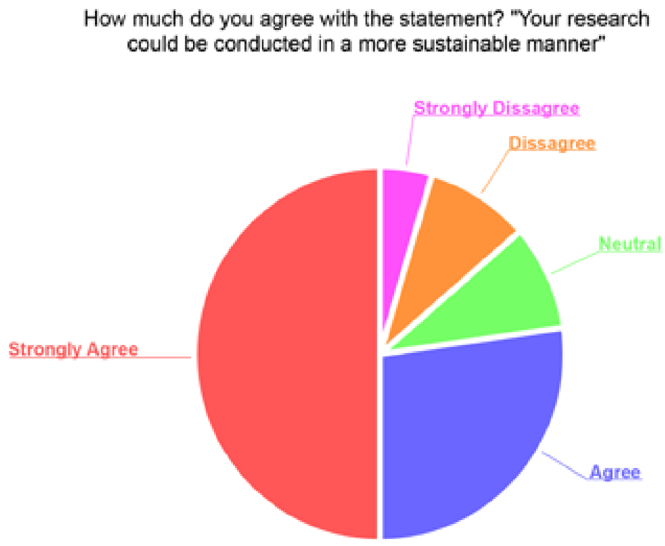

Figure 17: Sustainable research opinions
Author’s own (2020)

7.0 RECOMMENDATIONS

7.1 SMART WASTE MANAGEMENT

This recommendation targets the health and safety aspect of laboratory waste making it easier for laboratory staff to allocate waste correctly and opens the opportunity discussed in 6.3 to introduce additional lower risk waste classifications and ambitiously aims to introduce laboratory recycling into the waste system of more laboratories.

Though this may prove unachievable due to extensive contamination and regulatory restrictions in place there is still plenty of potential to optimize the current waste process and more accurately dispose of waste so that existing programs, such as the nitrile recycling mentioned in the literature review to be used in more laboratories.

The proposed solution would be a smart station that allows users to identify specific materials that objects are made up of and tells them the best way or the options available to dispose or recycle the object. Helps to address the issue that participant 6 presented

"Half of the people in the lab don't even know which waste goes into which one so they go and ask the postdocs "Am I doing the right thing, is going into the right bin?" So I... and it's not they are not being taught when you join the lab. The first thing they go through in the induction is where do you have to dispose what waste"
Participant 6

In simplifying the process these correct behaviours will be easier for inexperienced researchers to learn and it is more likely that they will develop better habits as they gain experience.

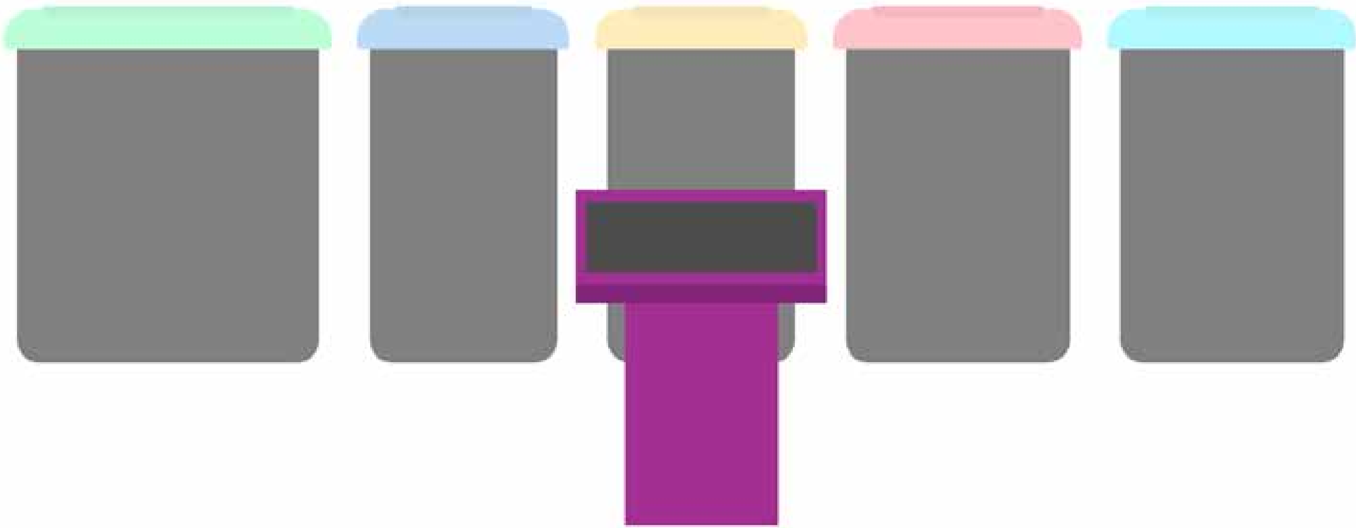

Figure 18: Product recommendation 1
Author's own (2020)

7.2 PERSONAL PIPETTE CLEANER

Understanding the possibilities for cleaning and sterilizing equipment to enable reuse and, more importantly the limits of this enables a strategy that can extend the use of products inorder reduce waste. As discussed with Participant 6 in semi-structured interviews an effective approach to improving the amount of uses from a single pipette tip is by performing a quick clean between uses When pipetting multiple reagents that can tolerate a small amount of contamination. This was simply done with a container of distilled water in this case.

This recommendation proposes improving upon this process with a small desktop pipette tip cleaning station that is able to be more effective in cleaning a tip between uses. Making situations in which miniscule amounts of contaminants does not affect the overall result also contexts in which a low quantity of new pipette tips are used.

This study has indicated that even small reductions in the amount of plastic pipette tips used could be a successful measure in reducing the overall waste produced in laboratories. A key to achieving this is by creating a tool that meets the needs below.

- Affordability
- Convenience
- Minimal desktop space required
- Appropriate for repetition
- Adaptable for different contexts
- Contamination control
- Is entirely autoclavable.

As can be seen in figure 18, this would not be a tool to replace existing sterilisation methods and would serve as a system for improving the use-life of products through improved cleaning methods for individual researchers.

This recommendation is not limited to pipette tips as it could be helpful in extending the product life of gloves, disposable tubes and other containers.

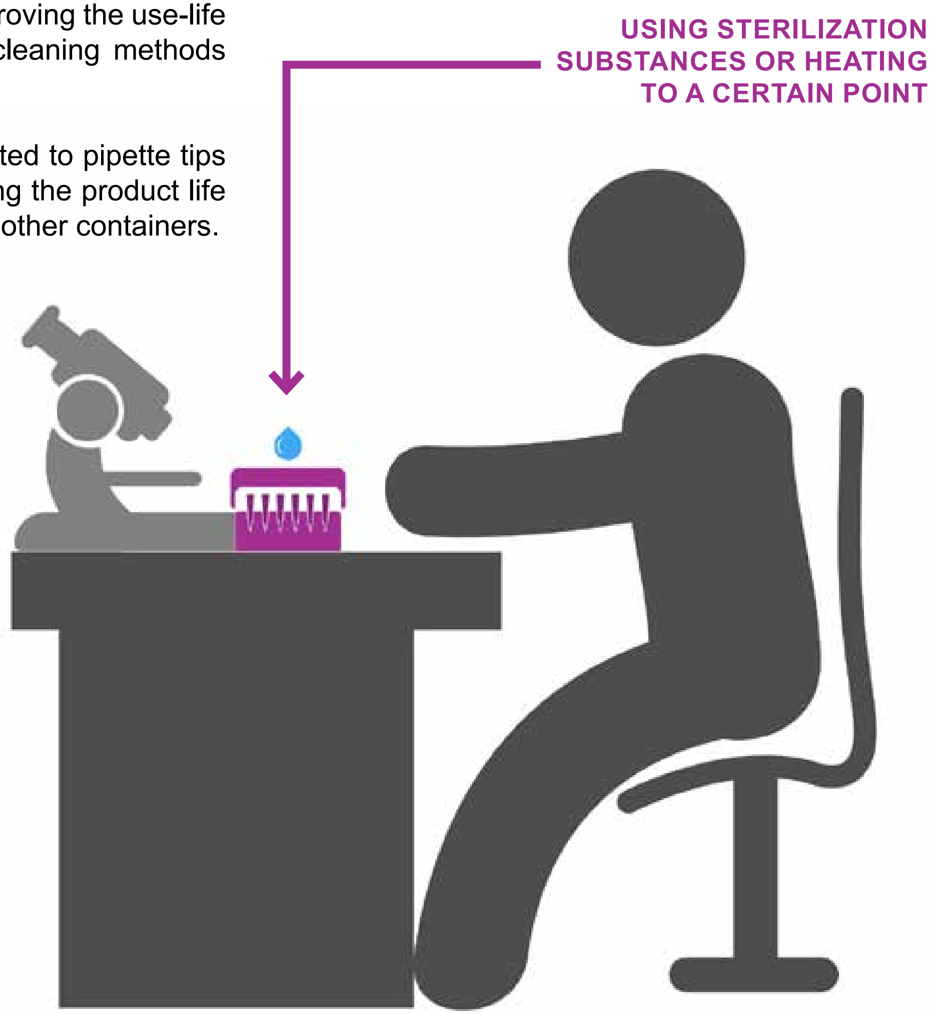

Figure 19: Product recommendation 2
Author’s own (2020)

7.3 GLOVE COUNTER DISPLAY

This recommendation targets influencing user behaviours by making them more aware of their use of consumable products.

The product could be as simple as a cardboard box with a mechanical component that counts each time a glove is removed and indicates it on the outside of the box. An alternative to this is a more integrated approach using technology that can (as figure 19 shows) display the quantity of gloves used per day or other set times. This data could then be used by laboratory managers for analytics purposes such as performing audits and keeping track of stock.

Figure 10 shows that there is a need for a solution to reduce the amount of gloves wasted as respondents indicate, it is the most commonly wasted item in laboratories. The conclusion made in "4.3 Equipment" Estimates that the bottom 25% of users could contribute 6.8 times more gloves than the average user out of the remaining 75%. This implies that reductions targeting the behaviour of some could impact the total waste of gloves drastically.

EACH TIME A GLOVE IS TAKEN THE COUNTER GOES UP BY ONE.

MAKING LABORATORY USERS MORE AWARE OF THEIR DAILY HABITS AND BEHAVIORS.

RESETTING EACH TIME NEEDED FOR EXAMPLE RESET AT THE START OF EACH DAY.

LONG TERM ANALYTICS AND LOGGING ALLOWS QUANTITY OF GLOVES USED TO BE TRACKED EASIER BY LABORATORY MANAGERS.

Figure 20: Product recommendation 3

Author's own (2020)

8.0 PROPOSAL

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8.1 DESIGN INTENT

The intent of this design is to reduce the amount of plastics going to waste in laboratories, making a significant impact on the everyday sustainability of laboratories

8.2 JUSTIFICATION

Research into this area has shown that laboratory plastics have a large impact on the environment and have seen little improvement since the widespread adoption of plastic lab equipment. The largest contributors to this is the contamination of equipment that makes the equipment unusable, then being destroyed through incineration which releases harmful toxic smoke into the atmosphere. Not only is this harmful, the high amount of waste is a toll on the budget of laboratories and research institutes globally with a constant supply of equipment being purchased to replace destroyed equipment. Designers can assist in creating new approaches to the creation of laboratory plastic equipment and to the waste system surrounding this that can give institutes and researchers more options when it comes to conducting lab work in a sustainable manner.

8.3 CONTEXT

Teaching environments

This context is simple to define, it is a laboratory in which practical teaching is conducted. This is where science students form their foundational knowledge around equipment use behaviours, practices and routines. This context is characterised by higher quantities of users, tasks that are low in frequency but high in quantity for example, students learning to identify pollen groups in a petri dish. This task may only be conducted 2-3 times per student however if there are 50 students this results in 100-150 dishes.

Waste management

This context involves the waste systems in laboratories. Characterised by the product use, product disposal, waste categories, storage of waste, and disposal method of waste groups. Furthermore it is heavily impacted by health and safety considerations and regulatory restrictions.

Personal laboratory user experiments

Laboratory tasks from for an individual. This context would allow individual laboratory users more options and more opportunities to reduce their own plastic waste. Possible locations include laboratory bench space or below bench storage.

Systems based overall laboratory

A system based approach to improve the overall sustainable practices of a workplace or community of laboratory users.

PHOTOGRAPHER | POLINA TANKILEVITCH | PEXELS

8.4 KEY CRITERIA

Affordability
Affordability plays a key role as many in this context have limited budgets and are in charge of their own purchases. The product must not be more expensive than existing reusable alternatives to disposables.

The costs of the product must be quantitatively justified and offer financial savings in the long or short term to be viable.

Accessibility
The product must take into consideration minorities with disabilities, including but not limited to reach/ clearance of people with mobility disabilities, blind user needs, hearing impaired user needs and vision impaired user needs.

Function
Product must reduce laboratory plastic waste in a way,with either a design for improved disposal methods, design for long term reuse or designs that will improve product use-life for existing products.

Usability
The need for ergonomic shape, a highly degree of usability and simple use is key as laboratory users often perform repetitive motions inorder to prepare for and conduct research tasks and the product must not add unnecessary stain to the users.

Complexity
The product should not be too time consuming as this is a key need for users in this context.

Flexible Use
Due to the very wide range of tasks conducted across laboratories the product must be adaptable and flexible in its use, meeting multiple needs or needs of high importance inorder to hold value in a laboratory.

Consistent
Consistency is important for any laboratory equipment, rigorous testing must be performed on prototypes to ensure that consistent results are guaranteed to a degree.

9.0 CONCLUSION

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PHOTOGRAPHER | CDC | UNSPLASH

This study into laboratory sustainability found that laboratory plastic waste has an impact that is a significant problem for global sustainability and is considerably under-addressed in terms of laboratory sustainability issues. Research methods that assisted in a deeper understanding included a literature review, an online survey and semi structured interviews with laboratory users and a laboratory plastic manufacturer. The literature review inspects the laboratory sector, materials and barriers with promising findings regarding environmental management systems, and research gaps in recycling potential in laboratories.

Results of the firsthand research indicated that gloves, pipette tips and tubes were the major waste contributors. Barriers to individuals improving their habits were shown to be single-use design, inability to sterilise and contamination. Through a grounded theory approach to analysing interview data it was found that key themes discussed were teaching environments, health and safety, routines and habits and, research logistics. Recommended approaches to improve sustainability target use of gloves, pipette tips, the reuse of items in order to extend product use-life, waste management systems, and user's behavioural awareness with three recommendations though future designs in this thesis are not limited to these. The limitations in the study prevented some alternative methods of data sourcing, given this alternative research could prove valuable in finding new perspectives and themes in this topic area. Following this report, designs targeting these key themes will be developed in the aim of improving laboratory sustainability.

10.0 LEADERSHIP INITIATIVES

PHOTOGRAPHER | AUSTIN DISTEL SUPPLUIED BY www.useproof.com | UNSPLASH

QUT Career Mentor Scheme
Student Mentee

- Professional Development
- Improving Portfolio
- Meet Professional Designers
- Personal Improvement

In early March I applied for the QUT career mentor scheme not knowing if it would go ahead during the early days of COVID19. Within this my goals are professional development, better understanding of the industry and to improve my odds looking for employment.

I was paired with Fatima, a QUT academic PHD with experience working in UX design around the world and studies in industrial design. We've discussed in-house design vs consultancy, PHD, portfolio and upskilling and she's helped me to develop a career plan and timeline. Her continued insights into my portfolio discussed opportunities will likely prove to be invaluable in progressing my career.

Kahoot! DNH 703
Study Tool for Cohort

- Practice Content for Exam
- Using Online Tools
- Helping the Cohort

As a part of adapting to the circumstances of COVID 19 and the isolation brought on with it, I wasn't able to study in a group the way I usually prefer. This is why I created an online game for learning some of the exam content and held a session to act as a 'quiz master' and take people through the game.

I had made flashcards with the exam content and used those to develop questions with diagrams hopefully teaching some of the content from the first 6-7 lectures of class. Figure X shows the game was 20 questions long with custom, I also created diagrams for some questions and with 15 people from the cohort using it to help them study so I would consider this a success.

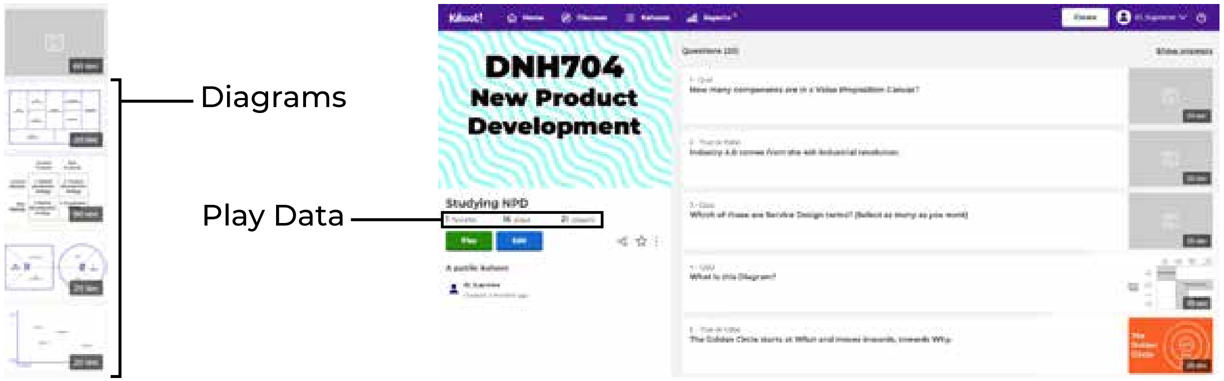


Figure 21: Kahoot Quiz Annotation

QUT Environmental Sciences
Eppendorf Cutting Tool

Portfolio Piece
Growing Network
Opportunity to Develop a New Product

I was put in touch with members of the QUT environmental sciences faculty by one of the DNH703 tutors, Dan Cook during the second week of semester 1 2020 as I indicated I was interested in studying bio-safety in laboratories for my thesis. I met Andrew Dickson, a manager for the laboratory, among other things we discussed the need for a tool that would make it easier to cut their small eppendorf containers that they propagate seeds in by 200+ at a time. As shown in figure X the eppendorf's needed to be cut just at the base after the seed began to grow to let the roots get through an agarose gel.

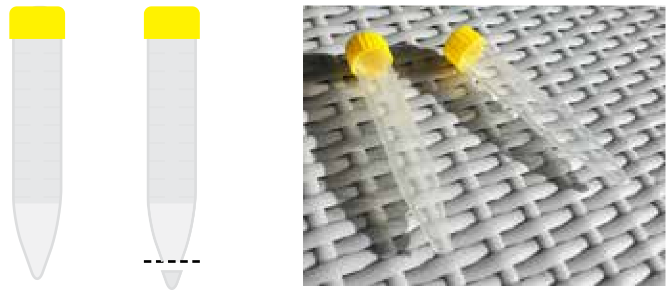


Figure 22: Test Tubes for Cutting

Figure 23: First Cutting Tool

After a brief discussion, it was decided I could 3D print a small block with a recess to hold the tubes while cut with a scalpel though after producing that concept (Figure 23) we decided a tool with a replaceable blade would work better, and be a sustainable product that would be used for longer. This is shown in the sketches shown in figure 24.

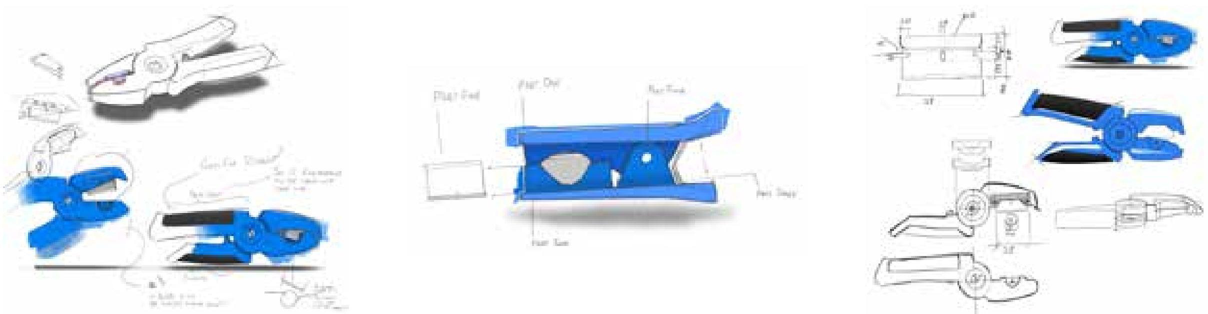


Figure 24: Cutting Tool Concept Sketches

Figures 25, 26 and 27 show the prototypes of the tool, were at the 3rd iteration now after a few meetings. The next step of this project is to refine to thew next prototype and include grips that will make the tool more comfortable to hold and a better system for securing the razor blade.

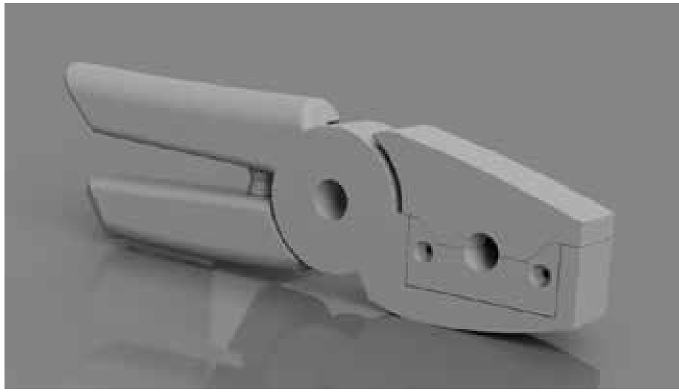


Figure 25: Cutting Tool Concept Model

Figure 26: Cutting Tool Prototype 1

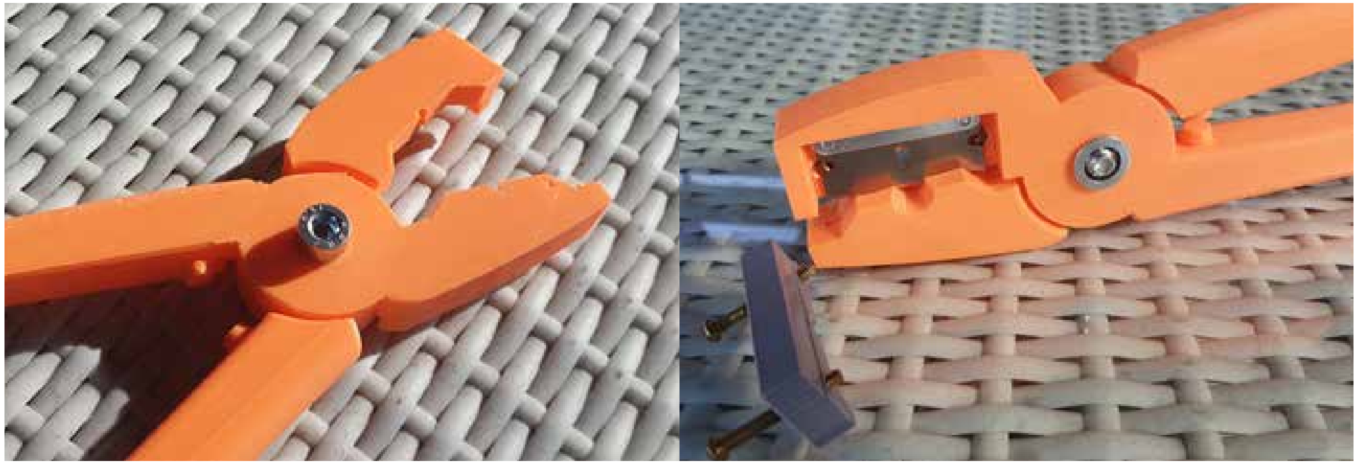


Figure 27: Cutting Tool Prototype 2

11.0 DESIGN JUSTIFICATION

11.1 INTRODUCTION

Thus far an understanding of the problem space surrounding laboratory sustainability challenges has been established with precedence given to the context of laboratory single-use plastics waste (lab plastics). As laboratories conduct research in a plethora of fields and disciplines, one dilemma that is present in all presents itself in the question “is the value of research worth the impact on the environment that the unsustainable plastic equipment usage will cause.” The cultural problem that seems to occur is that very few scientists would halt scientific progress and many researchers who have gone through their careers teaching and being taught these practices have grown comfortable with the normality of this.

A commonly used lab plastic that the survey and interview data in this report has indicated is a massive contributor to laboratory waste is pipette tips. The second stage of this report is the design process, undertaken to develop a concept for a product/system that could be used to address this problem with a focus on pipette tips. By targeting pipette tips and the reuse action in the “Reduce, Reuse Recycle” approach the goal of this product is to:

A: Reduce the amount of pipette tips purchased and disposed of by laboratories.

B: Maintain high standards of research.

C: Save laboratories money.

11.2 THE LABCYCLE SYSTEM

The product designed was the Labcycle System, a machine built for laboratory co-working spaces that uses eight removable washing tubs to clean pipette tips and small plastic tubes such as eppendorfs and conical centrifuge tubes. Each tub can be removed to take a contained batch of sterilized lab plastics to a desk or work bench to then use like a normal pipette or tube rack and then fill to wash.

Figure 28: Labcycle System.
Author’s own (2020).

11.3 SEQUENCE OF USE

Initial set up

This stage involves setting up the machine for normal use (A) and if there is a new type of equipment being washed or change of a equipment calibration in the settings (B).

Stocking with used lab plastics

In this stage users go about their normal work and fill one of the tubs with the plastic equipment they wish to wash. Then insert the tub into one of the drawers.

Wash sequence

The wash sequence involves 5 separate cycles; prewash (2 minutes), wash (10 minutes) rinse (5 minutes), ethanol spray (2 minutes) and drying (3 minutes).

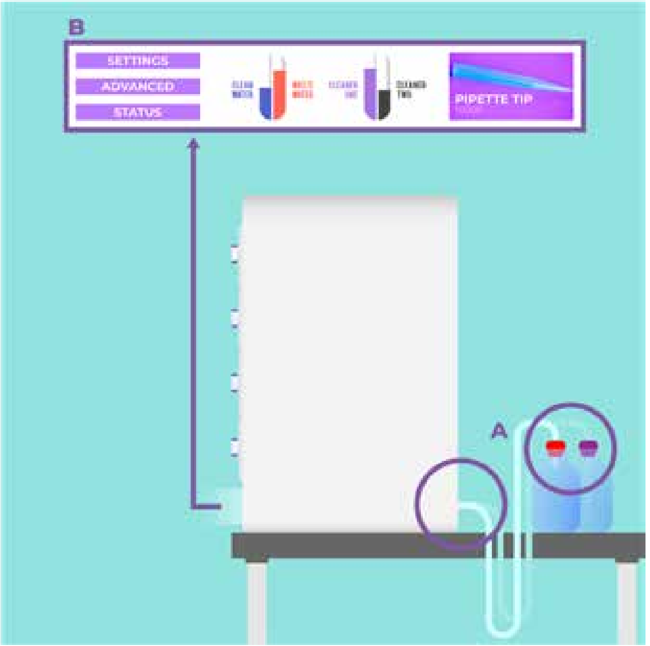


Figure 29: Set up of system.
Author's own (2020).

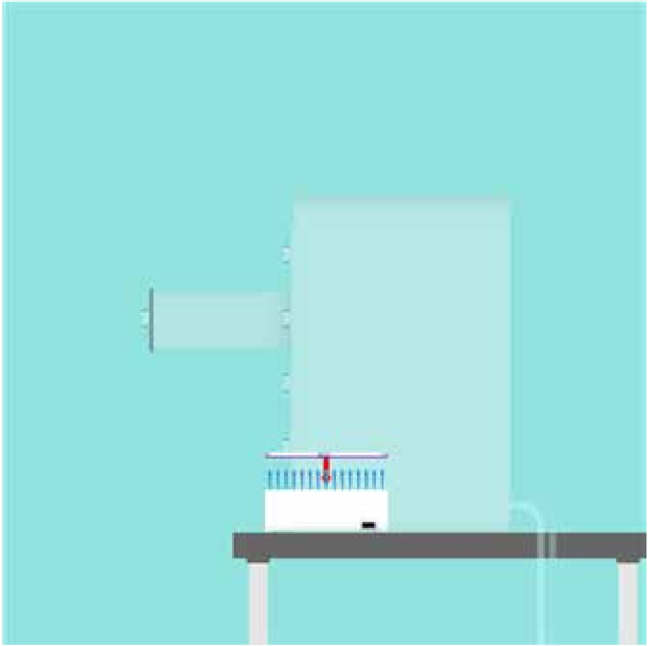


Figure 30: Filling/stocking system.
Author's own (2020).

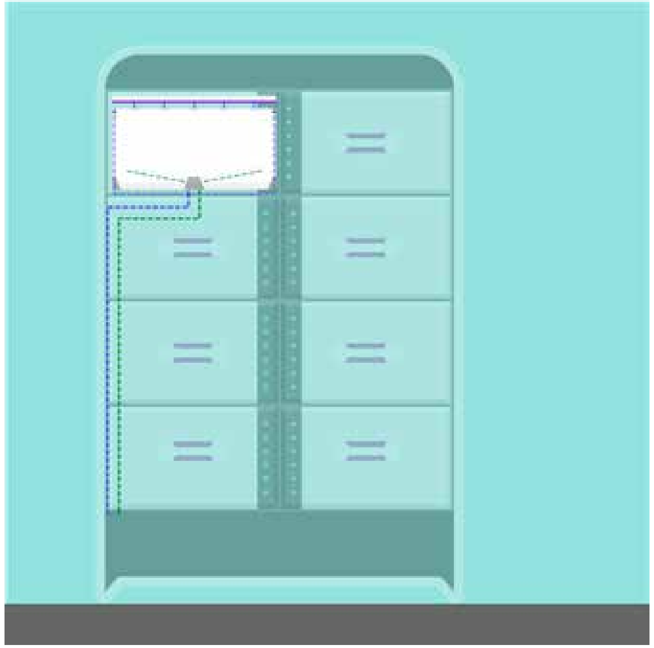


Figure 31: Wash sequence.
Author's own (2020).

Monitoring

The system can be monitored holistically to see the water usage, detergent and ethanol levels and the overall settings using the main user interface as well as individually monitored to see the progress of each drawer's progress.

Unloading and use or storage

Finally once the load has completed the wash sequence it can be unloaded. The machine will indicate that it is complete with green flashing lights on the mini-display for the drawer that is finished. The handle is turned to unlock it and then the tub inside is removed using the handles.

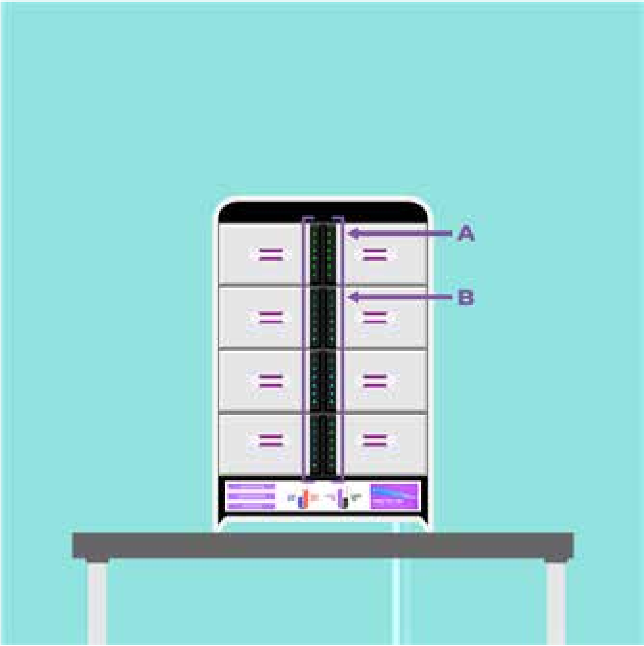


Figure 32: Monitoring of system.
Author's own (2020).

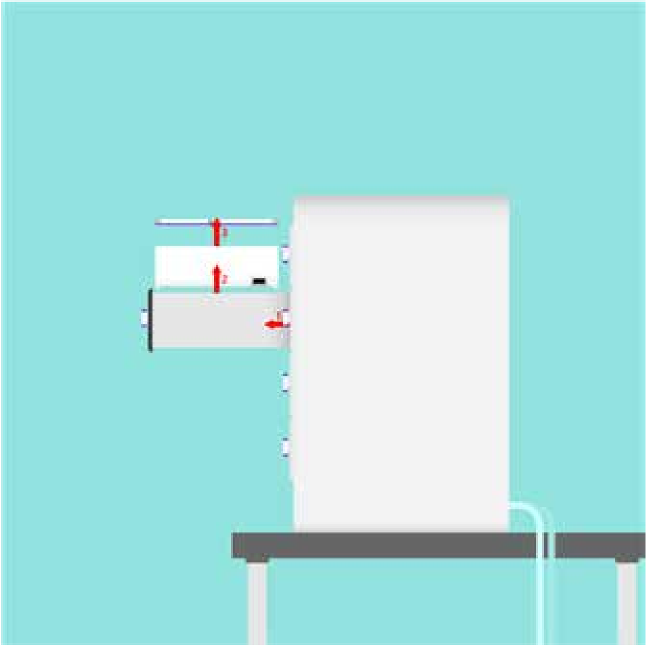


Figure 33: Unloading.
Author's own (2020).

11.4 PACT ANALYSIS

People

The users of this solution can be classified as "researched based lab users" such as students, industry researchers, and academic researchers. The fields and disciplines that divide these groups can be split into 3 groups as well. Those, for which contamination is a very high risk factor, those, for which it is a low risk factor and those that sit between.

Figures 34 and 35 show divisions that can be made between.

Figure 34: Labcycle users.
Author's own (2020).

Figure 35: Labcycle users assigned into contamination as a risk factor.
Author's own (2020).

Actions

Relating user's behaviours and actions to the context, users typically throw out pipette tips after a single use. Users in microbiology that were interviewed in the first stage of this report would typically dispose of pipette tips after any small amount of use or contact out of caution of possible contamination.

Two examples of the practices of this are below:

Example one

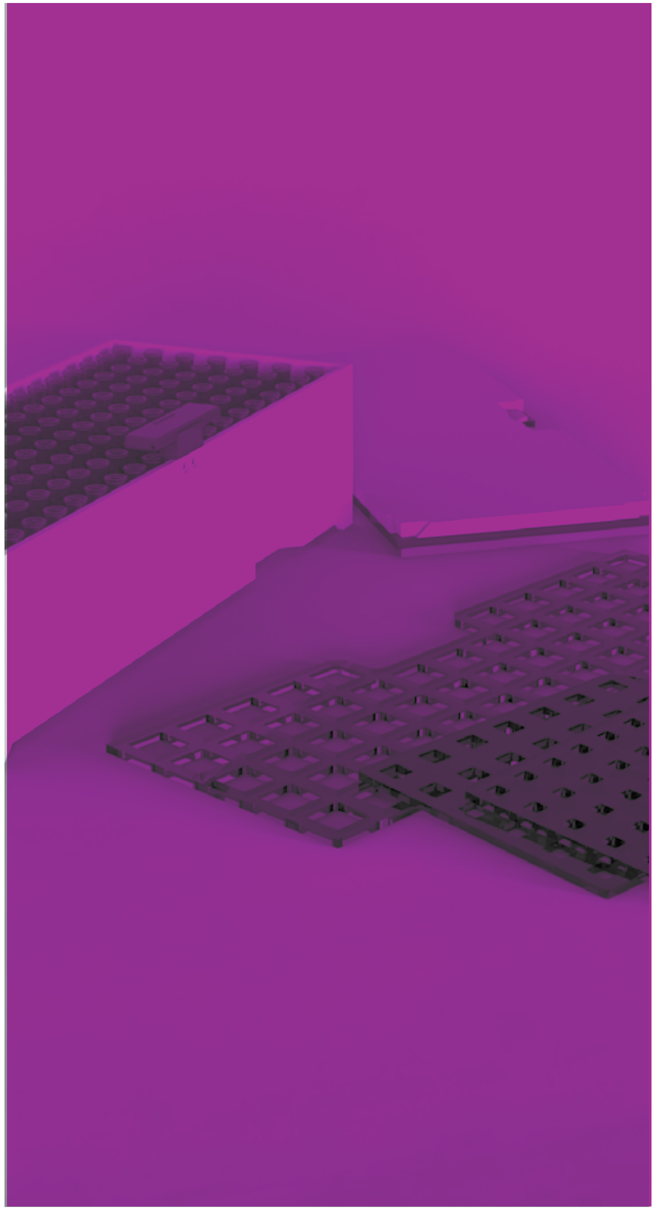
> If the pipette tip being used were to touch the edge of a beaker, or eppendorf that were clean or being set up, best practice is to dispose of that tip and get a new one.

Example two

> If a tip did not draw in the correct amount of a sample instead of trying again for the correct quantity it is to be disposed of and a new tip is to be used to draw the correct quantity.

These examples show the frequency of which these tips are changed and used. Consideration to this has had a great impact on the physical size and usability of the device.

The continuous and meticulous workflow of users must be adapted to inorder to design a device that will not add additional tasks or stages in research. Interviews indicated that users do begin with theory work to determine the premise and practical implementation of their experiments then spend extensive time preparing high quantities of accurate sample groups and experiments with near identical parameters. For this, it is important that laboratory plastics that are washed meet ISO 12771 (1997), the Australian standards for laboratory pipette tips.



Context
The nature of the physical environment laboratories encompass is highly consistent and meticulously monitored. Laboratories in Australia are classified by their PC Levels (Physical Containment) meaning that they must have specific amounts of ventilation, containment procedures, etc. Depending on the function of the lab. This product requires bench space, DC power ports, storage space, demineralised water and ethanol, all of which are common in the vast majority of laboratories.

Technologies
The technologies involved in this product are typical of glassware washing machines and of household dishwashers with a few alternative processes;

- A sterilization spray post wash to reduce the chances of microbial contaminants.
- An anti-microbial additive (BioCote, 2020) to the Polybutylene terephthalate used to manufacture the tub.
- Detachable gaskets for transporting waste water and clean demineralised water between the tub and main body of the device to enable the tubs to be removed from the rest of the device. This technology is commonly used in high end espresso machines.

11.5 DESIGN PROCESS

The design process occurred over a 15 week period in QUT's second semester 2020 period from the 20th of July to the 2nd of November. Milestones during this period are outlined in figure 36. Though due to the nature of iterative design, these stages are not strictly adhered to; instead, serving as a guide to keep the development on-track.

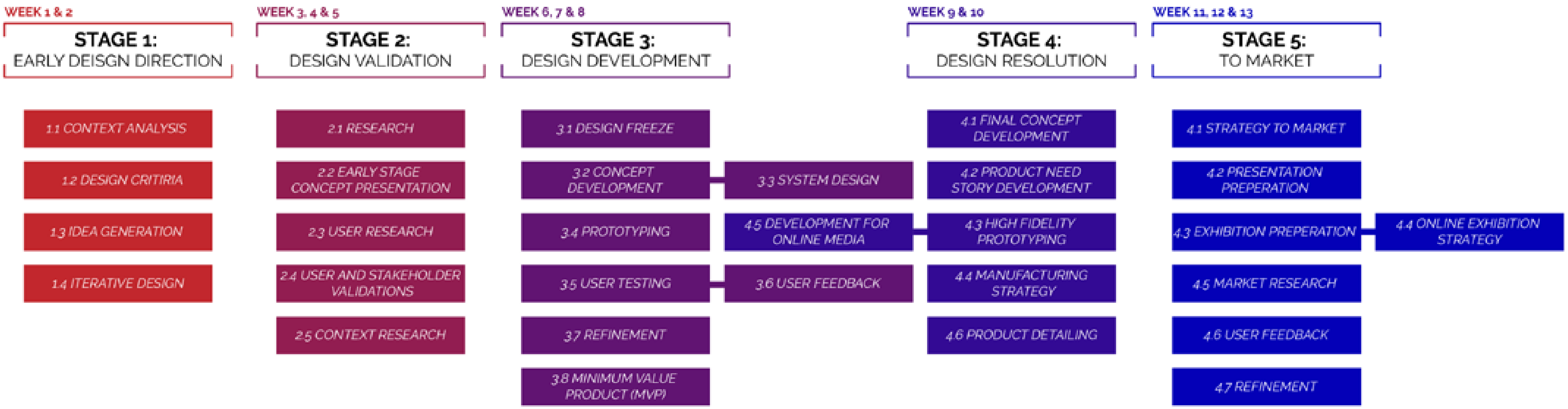


Figure 36: Entire project key stages
Author's own (2020)

11.5 VALIDATION

The validation process for the Labcycle System was designed to receive user validation on the concept as a whole and validate the usability of the design with simulated laboratory tests.

For the first component an interview participant was consulted, advising on feasibility of aspects of the design and suggesting updates or additions.
Figure 37 Shows a meeting with the participant.

The second component of validation involved devising a rough test with the participant for a different volunteer to participate in (this was due to the limited time of the user). Then setting up and running the test using a non-lab user participant under the direction of the laboratory user.

The test, focusing on workflow and task completion, tested:

- Pipetting clean tips from a new supply and ejecting them in the tray after use.
- Placing the used tips in the machine and alternating to a new set of tips.
- Alternating between trays.
- Last, using tips from the prototype then ejecting them into a different location.

Figure 37: User validation with participant
Author's own (2020)

Figure 38: User testing
Author's own (2020)

11.6 BUSINESS CASE

	ANALYSIS
Key Partners	Stakeholders that would make up an essential part of the business of the Labcycle System are made up primarily of distribution channels, Universities, groups that oversee large amounts of laboratories and regulatory boards. Operational Health and Safety (OHS) officers and laboratory managers within these groups are also very important stakeholders to consider as they are often in charge of specifying equipment for the laboratories that they are supervising.
Key Activities	Key activities that require attention and care are product certification and testing with rigor as this will remain a barrier to market if internationally recognised certifications are either not met or not applied for. Maintenance and customer's ability to repair or replace parts is an important part of customer care and sustainability post sale of the product.
Key Resources	*Plastics Specific Detergent* Detergents could be sold as a complimentary product with a plastic specific detergent that suits the system best. This ensures that sanitization standards are met without inferior products that may cause issues for the machine.
Value Proposition	*Monetary Value* As a rough estimate, with an additional three uses (four uses in total) using the minimum capacity of the device (one drawer full) laboratory managers are predicted to save $13,140 AUD and 87,600 plastic pipette tips. Depending on the value of tips used and of other equipment washed this number will vary and is likely to increase as this estimate is conservative. With a high degree of use this estimate could easily go up by 2000% if all drawers were used multiple times on a daily basis *Environmental Value* As previously indicated environmentalism is an increasingly urgent, important factor that all industries must consider when planning and building the logistics of their business.
Customer Segments	Customer segments depend on three factors of use; variety of items being washed, quantity of machines used per laboratory and frequency of use. Commercial or industry customers with a higher quantity of machines and frequent use will require more customer service. This includes regular maintenance, repair and additional customer service. This being said, this product aims to be adaptable and flexible for situations that involve different use from multiple individuals, more likely used to this potential with a customer segment made up of academic researchers and small-medium laboratory teams.

Table 6: Business Case Points
Authors own, 2020

11.7 DESIGN DISCUSSION

CRITERIA	DISCUSSION
Safety	Labcycle is designed to limit the amount of exposure people will have to the equipment being washed with no physical contact being necessary for pipette tips and limited gloved handling for tubes. This will need to be explained in detail within an operation manual.
Manufacture	Manufacture related benefits this design offers are the high quantity of identical parts that reduces tooling costs to produce a product of this complexity and size. Negatives of manufacturing is the large amount of physical components and mix of materials and manufacturing methods. This includes sheet metal bending, injection molding using PBT, HDPE and PVC with combinations of antimicrobial additives and glass treatment and cutting.
Technology	The technology used in the Labcycle System is often used in many commercial cleaning devices and products, though the methods and technologies used to clean would need significant testing and development before it reached a feasible stage for use and sale.
Aesthetics	Design aesthetics for this product aimed to not add additional clutter to a laboratory product ecosystem as excessive colour coded items and equipment is contained in high end laboratories. There is a possibility that colours and aesthetics could confuse purpose and context for this device in some laboratory settings, this is why a minimalist approach has been chosen to define the aesthetics.
Sustainability	As sustainability is the main focus of the context and usability of this product it is clear that to use this product is a sustainable effort. The second aspect of sustainability is the products repairability, recyclability and lifecycle. The product is made up of many different materials and uses antimicrobial additives, therefore traditional recycling is not always possible for all components. This is why it is important to extend the product's lifespan through repair and maintenance.
Limitations	Time restrictions limited the amount of progress made on the design, further development into usability and function could have been progressed towards a longer timeline. Budget impacted the prototyping and materials used in prototypes, without this limitation working prototypes could be achieved as well as prototypes using specified materials such as sheet metal and powder coated surfaces.
Further Research	Further development of this product will be needed before it is a at a production level, this is because technical aspects of the design are beyond the scope of an industrial designers strengths and abilities; this being said, this concept should be able to serve as an excellent proof of concept to explain the value, design, function and usability of the product. Improving upon and developing a functional MVP (Minimum Value Product) would be a next step.

Table 7: Business Case Points
Authors own, 2020

11.8 DESIGN JUSTIFICATION CONCLUSION

The Labcycle laboratory plastics cleaning system is a design that addresses the excessive use of single-use plastic equipment in science through a method of reuse to extend the lifespan on equipment such as pipette tips and small plastic tubes. Labycle offers laboratory managers and end users incentive to reduce their waste with significant savings on the cost of large quantities of equipment and reduces the amount of plastic incinerated each year by half to three quarters. This is done through a system that cleans lab plastics using a method specific to that type of equipment to sterilise them and contain them in removable, portable trays that can be used by scientists. This product has the potential to offer laboratories an alternative to the tough question, “is this research worth the unsustainable waste it will inevitably produce?” helping laboratories to enter a new chapter of sustainable science.

11.0 REFERENCES

PHOTOGRAPHER | PAWEŁ CZERWIŃSKI | UNSPLASH

Ali, U., Karim, K., & Buang, N. (2015). A Review of the Properties and Applications of Poly (Methyl Methacrylate) (PMMA). Polymer Reviews, 55(4), 678–705. https://doi.org/10.1080/15583724.2015.1031377

Australian Government: Department of Health, Office of the Gene Technology Regulator (OGTR). (2012). Guide to Physical Containment Levels and Facility Types. http://www.ogtr.gov.au/internet/ogtr/publishing.nsf/content/explanatory-3/$FILE/FacilTypesV1-2.pdf

Australian/New Zealand Standard. (2010) Safety in Laboratories: Part 3 Microbiological Safety and Containment. (AS/NZS 2243.3:2010). SAI Global database.

Betz, U., Balling, R., Goncalves, J., Magni, S., Mombaerts, L., Oldano, A.,& Skupin, A. (2018). Curious2018 - Future Insights in Science and Technology. (1st ed.). Springer. https://doi.org/10.1007/978-3-030-16061-6

Bhanot, D. (2016, December 8). Characteristic properties of commonly used laboratory plastic materials. Lab-Training. https://lab-training.com/2016/12/08/characteristic-properties-commonly-used-laboratory-plastic-materials/

BioCote. (2020). Antimicrobial Technology Specialists. BioCote. https://www.biocote.com/

Drues, M. (2015, April 30). Can We Design Medical Devices To Be Reprocessed Without Killing People?. MED Device Online. https://www.meddeviceonline.com/doc/can-we-design-medical-devices-to-be-reprocessed-without-killing-people-0001

Dunn, G. (2016). Expanding RightCycle by Kimberly-Clark Professional Press Release. Kimberly-Clark. https://www.kcprofessional.com/umbraco/rightcycle.html

Exeter (2019, September 20). Exeter researchers help to raise awareness about the amount of plastic waste generated in labs. University of Exeter. http://www.exeter.ac.uk/cornwall/news/articles/exeterresearchershelptora.html

Flick, U. (2004). Triangulation in qualitative research. A companion to qualitative research, 3, 178-183.

Hanlon, D., & Ramiń, J. (1999). Safety practices with laboratory glassware. Chemical Health & Safety, 6(6), 17-20. https://pubs.acs.org/doi/pdf/10.1021/acs.chas.8b06606

Howes, L. (2019). Can Laboratories Move Away from Single-Use Plastic?. ACS central science, 5(12), 1904–1906. https://doi.org/10.1021/acscentsci.9b01249

Holden, A., Loyd, N., & Blanchard, L. (2011). A Practical and theoretical approach to sustainability using process improvement. In IIE Annual Conference. Proceedings (1). Institute of Industrial and Systems Engineers (IISE).

Holstein, W. K., & McLeod, T. S. (2013). Research and development: Types Of Laboratories. Encyclopædia Britannica. https://www.britannica.com/topic/research-and-development

ISO. (2012). Medical laboratories: Requirements for quality and competence (ISO 15189:2012). ISO database. https://www.iso.org/standard/56115.html

Lee, B. K., Ellenbecker, M. J., & Moure-Eraso, R. (2002). Analyses of the recycling potential of medical plastic wastes. Waste Management, 22(5), 461–470. https://doi.org/10.1016/S0956-053X(02)00006-5

Lopez, J. B., & Badrick, T. (2012). Proposals for the mitigation of the environmental impact of clinical laboratories. Clinical Chemistry and Laboratory Medicine (CCLM), 50(9), 1559-1564.

Lunn, G., & Sansone, E. (2012). Destruction of hazardous chemicals in the laboratory (3rd ed.). Hoboken, N.J: John Wiley & Sons.

Molé, P.,N. (2019). Create a strong safety awareness across biosafety levels. Chemical Engineering Progress, 115(4), 33-40. Retrieved from https://gateway.library.qut.edu.au/login?url=https://search.proquest.com/docview/2218169177?accountid=13380

My Green Lab, (2020). Resources: Waste. My Green Lab. https://www.mygreenlab.org/waste.html

NASA Global Climate Change and Global Warming: Vital Signs of the Planet. (2020, March 31). Global Climate Change: Evidence. NASA. http://climate.nasa.gov/evidence/

Newswire. (2016, Oct 03). Laboratory glassware and plasticware market by product, plasticware, end user - forecast to 2020: "laboratory glassware and plasticware market, by product [glassware (pipette, flasks, containers, petri dishes, slides), plasticware (pipette, laboratory beakers, racks, storage boxes)], end user (diagnostic center, pharmaceuticals) - forecast to 2020". PR Newswire Association. https://gateway.library.qut.edu.au/login?url=https://search.proquest.com/docview/1825283328?accountid=13380

Ross, J., Penesis, J. & Badrick, T. (2019). Improving laboratory economic and environmental performance by the implementation of an environmental management system. Accreditation and Quality Assurance 24, 319–327. https://doi-org.ezp01.library.qut.edu.au/10.1007/s00769-019-01388-6

Standards Australia. (1997). Plastics laboratory ware -- Disposable serological pipettes (ISO 12771). https://www.standards.org.au/standards-catalogue/international/iso--other/iso--12771-colon-1997

Thermo Fisher Scientific. (n.a.). Plastic Materials Selection. Thermo Fisher Scientific. https://www.thermofisher.com/au/en/home/life-science/lab-plasticware-supplies/plastic-material-selection.html

Thielking, M. (2019). Labs rack up big energy bills and produce a ton of trash. Many are trying to become more eco-friendly. STAT. https://www.statnews.com/2019/05/15/labs-push-for-sustainability/

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

Voelker, R. (2019) Contaminated Duodenoscope Saga Continues. JAMA. v322(13):1246. https://doi.org/10.1001/jama.2019.15402

Whiting, L. S. (2008). Semi-structured interviews: Guidance for novice researchers. Nursing Standard (through 2013), 22(23), 35-40. Retrieved from https://gateway.library.qut.edu.au/login?url=https://search.proquest.com/docview/219839081?accountid=13380

Wright, H. A., Ironside, J. E., & Gwynn-Jones, D. (2008). The current state of sustainability in bioscience laboratories: A statistical examination of a UK tertiary institute. International Journal of Sustainability in Higher Education, 9(3), 282-294. http://dx.doi.org/10.1108/14676370810885899

12.0 APPENDICES

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12.1 APPENDIX 1 | TWITTER LINKS

https://twitter.com/eLifeCommunity/status/1173824161950687233
https://twitter.com/GreenLabsBham/status/1174013613092364300
https://twitter.com/BenteBenedict/status/1173986451907862534
https://twitter.com/HainerLab/status/1174054346968850432

12.2 APPENDIX 2 | INTERVIEW QUESTIONS

Sustainability in Science

Semi-structured Interview *(Lab Researchers)*

Time Limit (0:25) | Check Checkup (0:15) | Check audio and recording (0:00)

Request consent form confirmation prior to the interview.

How does your laboratory deal with waste?
- Strict or relaxed measures?
- Consistent or consistent?

Do you think your lab offers you sustainable options when it comes to which equipment you use?
- What are they?
- Do you think there are any drawbacks for using sustainable options?

What kinds of tasks do you perform that results in disposable equipment becoming contaminated waste?

What categories do you split waste into?
- How does this work
- Who disposes of it, etc.
- Are there any give back schemes with suppliers you're aware of?

Do you feel like you always know how to best dispose of an item?
- What guides / rules do you follow?

Which situations can you use reusable materials like glass or sterilized plastics and which situations do you need to specifically use disposables?

What plastic items do you use repeatedly?

What do you think are some of the largest sustainability issues in your research?

Interview for Manufacturing

What kinds of consumables do you guys make/supply.
- Where do you supply them? Who are your users and what kinds of quantities do you supply?

How do you know what happens to the product's end of life?
- Is there a system in place to monitor this that hospitals use?
- Are you kept in the loop?
- Do you have any knowledge of where it's disposed of?
- Are there any take back schemes you're aware of?

How much has the medical / experimentation consumables trade / industry changed over the time you've been in it?
- What other products do you get to work on?

What standards do you stick to for preventing contamination?

Are there products you have that work with the consumables you supply?
- What other products do you sell?
- Are there any that are designed to try and assist with sustainability?

What kinds of packaging do you supply goods in?
- What materials are these made from?

12.3 APPENDIX 2 | INTERVIEW CODING STRIPES EXAMPLES

Nick 0:02
Hey, no worries. Alright, so I'm noticing the survey you didn't mention much about your experience, but you were just telling me now. What's your experience in laboratories? How many? How many years?

P6 Biswa 0:13
Oh, I've been in the lab. Like, I've done my kind of realm projects in undergrad. I'm not counting them, but like, post undergrad. My masters and research experience I've been working in a lab full time of 2013. Okay, I'm pretty old. So different kinds of labs, but mostly biochemistry, molecular biology labs. So the setup is very similar. So a lot of glassware, lot of beakers a lot of plastics. So I've seen a lot of I was also guilty at one point you I wasted a lot of stuff, plastic stuff. But then what caught the attention is one of my postdocs in the previous lab worked in India. And he was like, wasting a lot of plastic. So why not glass? I mean, There are certain places where you can't use glass because you can't recycle them, you need to have it as clean as possible for every use. So we have to depend on plastics. But there are certain cases, or more cases where you make a gel, or you're doing some sort of routine purification, which is crude. And you're going to a step, which is the main purification, so you can always avoid plastic there. Okay, so nowadays, I mostly use glass. And I use them. So in our lab, they're like, they're like 20, because I'm just saying, roughly, so for people who have like all of them have divided with size. And so you keep using and reusing them until you reach a spot where you can't use something which has been washed, it has to be sterile out of the tip box and then use it throw it away. Yeah, so that has minimized my use of plastic by about I would say 50%, which is great. I really feel good about this.

Nick 1:51
Okay. Do you think is that the approach most people take in your lab?

P6 Biswa 1:54
No, not most of them. Use throw, use throw.

Nick 1:57
So you have a bit of control over exactly how you conduct experiments when it comes to what materials.

P6 Biswa 2:01
Yeah, more or less, because in our lab, it's only till the last stage or the second last stage is when you do something novel. Every other thing is very routine work. So you have, you totally know what you're going to do. It's the same process over and over again, just a different peptide or a different system. So your glasses use can be totally controlled.

And you can use plan it according to what you want to do.

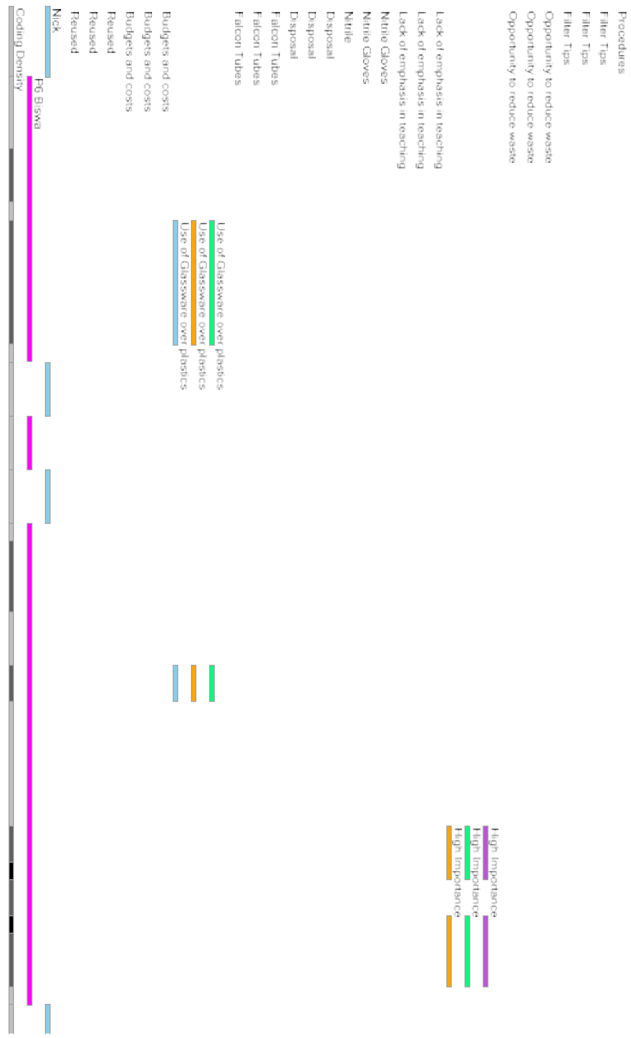
Yes, I use the same six or seven glassware every day. So it's totally up to you. Unless somebody has borrowed it, and I can't find it, then I have to, but I always prefer glass.

Unknown Speaker 2:33
Okay. Do you have you done any experience with like, so I know you're saying, molecular biology, but have you done more general stuff? Do you find there's a big difference when it comes to what things you can use in molecular biology versus sort of more general stuff.

Unknown Speaker 2:51
Okay. So, in molecular biology, as I said, there are a few instances when suppose you're doing some sort of Like a PCR experiment, maybe you're doing gene sequencing or something like that, they have to be really pure. So you have to be like as sterile as you can. So you can't like I would say, there are certain labs in which you can totally about plastic like zilch, we can like there are computational labs there, like even civil engineering, chemical engineer labs, where you don't really need that much appreciation or, like, you can go out with contaminants. I mean, contaminants are not even part of the worry. They're like, just normal routine work. But in our case, since we, in molecular biology, especially, contaminants play a big role, and they can totally change your system, even a little bit is added, or it goes by mistake. So it I would say in our kind of lab in our kind of setting, we tend to use more plastics, like single use plastics

Nick 3:49

1 / 8



1A

Is part of it, because it's cheaper. Is that a big part of it as well or does that?

Unknown Speaker 3:55
yeh, it's cheeper, like it like we don't even have to go to a third party. We just put it in order. In the uni gets it in either the same day or the next day, clean, easy to come by and cheap, convenient.

Unknown Speaker 4:09
So your lab clearly offers you sustainable options when it comes to like, choosing how you want to run your experiments. Do you think most labs do?

Unknown Speaker 4:16
No, I mean, there's there's nothing like the lab gives you like, it's all there. It's what you have to choose yourself, like the lab. You get access to the lab, you've done all the inductions. You see what people have been using, it's your choice whether you want to use glass or because you can always use glass for everything, but then you would know that you might end up with something which might give you a false result. So you have to be careful where to choose what to use, but it's totally upon you.

Nick 4:40
Okay, got it. Like going through your bachelor's degree and your PhD and everything. Do they put much emphasis on sustainability? Do they try and encourage?

P6 Biswa 4:51
In India? Certainly not. Now I've never like come I don't know now but I don't think it has really changed unless you actually go to a lab setting and you have a senior like engineer. We have a strong senior junior culture. So they'll come and train you. And even there are cases when they don't know themselves because the culture is not there. Sure. So and if you ask for classroom teaching, no, they don't teach you it's, it's only when you have a very enthusiastic senior is like, Oh, I have done it this way. I think it makes a difference. You can do it up to you. But there is no such formal training process where they tell you no, don't use plastic. So avoid

Nick 5:23
teaching in India, it's more difficult to try and be sustainable?

P6 Biswa 5:29
I don't know. I mean, it's the same things in the lab we find here and there. So there's an equal opportunity for you to use glass there. But again, the same thing, it's convenient to use plastics, it's cheap.

Nick 5:39
So do you ever like to have plastic things that you re-wash and reuse?

P6 Biswa 5:46
plastic because of course, so we have both plastic and glass because so they use plastic because like you wash them and you reuse them. So they can be counted as glass in the sense that they are used so they are not thrown away? Do you

Nick 5:58
ever wash and reuse eppendorfs or like, the centrifuge...

P6 Biswa 6:01
like the tips. Yeah. Oh, yeah. The centrifuge tubes. Yeah, they are reused. Yeah. So the 50 mil to 30 mil tubes there are reused, because we have only and they're really expensive. They're really thick plastics. Yeah, they come with the vendor in the centrifuge. And they are reused.

Nick 6:18
Oh, yeah. And but the pipette tips always disposed of in sharps, right?

P6 Biswa 6:23

Yeah. So I'll give you an example. Like, we don't have plastics, we only are plastic tips. But suppose I make you a gel. So I have to add 10 samples in 10 lanes, okay. They're all different samples, they can be cross contaminated. But I've seen that if you have a big beaker of water, and you just wash the tip a few times it is dissolved in the water and goes away and spreads. And it even if you get back a little, it's so negligible compared to the stuff you're gonna add the next time, you can pretty much use one tip to do all 10 lanes. So I've used 10 or nine less tips right? So this is how I try to

Nick 6:56
it really depends on the task and it's up to your discretion.

But if I need to do, this has to go to a publication. I can't afford to have impurity, maybe I would not do that. But for regular gels every day, I would just use one tip.

True, okay.

Do you think there was an option to wash pipette tips would the university try and do that, like if there was an option that was proven to wash preventives effectivly.

I think Yeah.

But maybe not. Maybe just to be safe. You would not use it for your applications, but maybe it made more everyday stuff viable.

P6 Biswa 7:25
Yeah. I mean, like the like, like this thing has been, like I always use different tips. Like even though I've been using, like I've been cutting on plastic, even in this lab, like, a year back. I was still using, like different tips for different names in the gel, because I was like, maybe picking a little contaminant and there's a Chinese postdoc in my group, and he's been working in this field for 20 years. And he's like, No, you can do this. I mean, I made gels every day and he does four or five days a week. So it's always a learning curve. I'm pretty sure if you spread this around there more people will take this up.

Okay, what kinds of like, what different pipette tips do you work with? How many do you think you work with in a, in a week or?

So. I mean, we use pipette tips almost every day. Yeah, so you have filter tips. So we use filter tips only when you're using a highly concentrated acid and you know that if you suck it in the pipette, it might just corrode. Otherwise use normal tips. And just single-use.

Nick 8:23
how to the filter tips work?

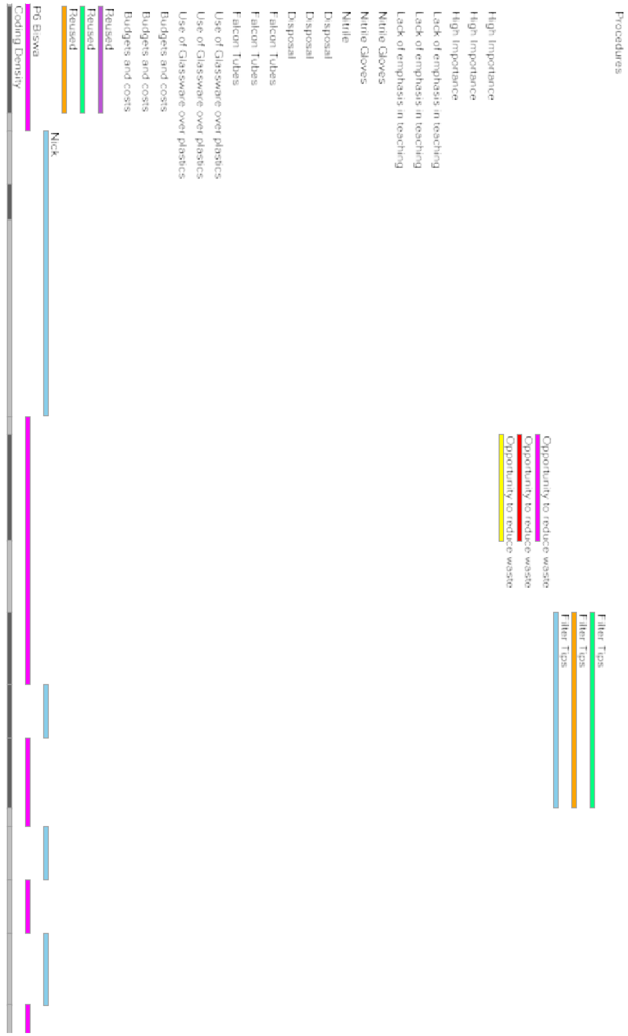
P6 Biswa 8:24
so it's like it's like a normal tip. But if there's like a, like, you know, like a cigarette butt so the same material, but a little better with little line that sit on the top, so it basically stops the asset from going in. Oh, I see. There's a layer basically. So it just blocks.

Nick 8:38
Okay. Interesting, but it's the same plastic?

P6 Biswa 8:41
Same material separately layer.

Nick 8:47
So do you want to elaborate maybe a little on what kind of tasks you do that produce the most waste or that produce waste that you think is avoidable? That is kind of like you just have to do it.

P6 Biswa 8:59



Like for example routine expression purification. Like, before I met you I was talking to this guy is like a friend, collaborator, of sorts. And I asked him, I'm just giving this interview, what would you say? I use plastics all the time. I don't use glass, even if I have to measure something, I take a plastic Falcon that is totally unnecessary. Like, what he does is what I'm assuming he does is even if he has to add, let's say 20 mil of something to 10 mil of something, he'll just take two Falcon tubes, add them, put it in the system and then throw it out. Do you

Nick 9:31
do you have to throw those out? Can you put them in washer or?

P6 Biswa 9:34
You can just keep it because you can use the same buffer in it again and again. Can

Nick 9:37
other people use those? Sorry, Falcon tubes.

P6 Biswa 9:41
Yeah, Falcon yeh, we call them Falcon tubes, because they're made by a company called Falcon.

Nick 9:45
Okay. So if you watch these falcon tubes, can other people use them then? Or is it just like you've used it? That's your responsibility now.

P6 Biswa 9:52
See, technically, if you've used that Falcon view to measure, let's say ACL, so any other guy can measure keep measuring ACL in that technically. But it's a matter of trust, I suppose. And no, I don't know what he's done in it.

Nick 10:04
And often you don't want to run the risk, I see.

P6 Biswa 10:06
exactly, it's a bit it's more of a risk factor. Like you don't know what he's done. So it might fuck up my Exeriment, right?

(Unrelated)

okay, So yeah, if unless I know that it's not gonna fuck my experiment up I'm like, Yeah, I can do it. But if I know that this might do some sort of a damage to my system or my experiment and better not touch it even though I know the guy really well I know is working ethic enough but I stil do.

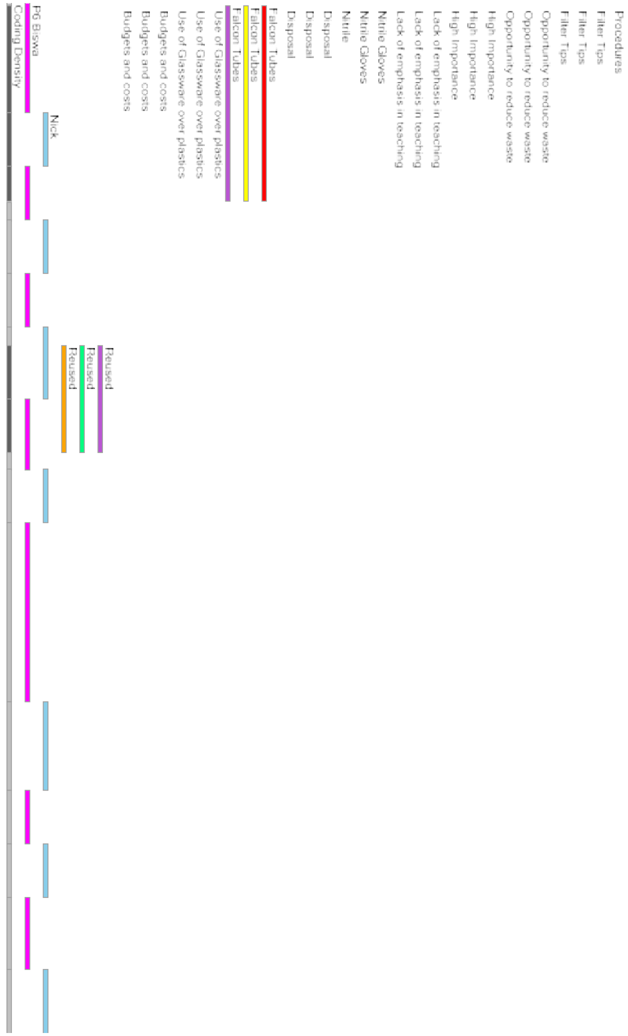
Nick 11:01
So you do have to be very careful and think, think critically about how you're going to use things and do so like two people often just accidentally slip up and they use something and it gets contaminated. Like how often does that happen?

P6 Biswa 11:14
I mean people wouldn't tell us. If, like, if I do something, and I know it was damaged, I would rerun it.

Nick 11:20
Yeah.

P6 Biswa 11:21
And then it's only if I'm being questioned, like, why you're doing it again then I'll tell? like nobody tells anybody this, unless you like really?

Nick 11:29
Unless it costs a lot of money ha ha.



P6 Biswa 11:30
Yeah. Yeah. So but yeah, if a similar thing happened to me, I would just rerun the experiment or redo the whole process.

Nick 11:38
Does it often have like situations where it ends up costing lots of money? Or does it often like can a contaminated experiment just be detrimental?

P6 Biswa 11:48
It can cost a lot of money depends, like I'll give an example. It's very normal with protin expression.

Nick 11:54
It's cheap. Like, lab wise, it's cheap. I mean, it doesn't cost a lot of money. But if you're doing a civil expression, with labeled material like isotopes. So isotopes cost money. So it's the same process just that the other using carbon 12, using carbon 13. And that becomes very expensive. 100 times expensive. So you might get away, you would probably get away with, you know, you're supposed to like, okay, just do it again. But if you had, if you're using 13C, you have to redo it, because this can be used, but you might get, like, what are you doing? He might just be mad at you because of the money involved. Yeah. So rather than thinking about what you're working with, we do it in a way that we take every step carefully, even if it's cheap or expensive. So the work ethic comes out in the sense that you're doing it correct every time. Yeah. So it's, it's not only when it's expensive that you have to be careful, it's more general done. Okay.

What do you guys do, something different, but what do you guys do with repetitive boxes, do you?

P6 Biswa 12:52
Yeah, so we autoclave them first, okay, because sometimes you don't need to autoclave them. But more often than not, you do have to autoclave because you need a sterile environment to grow cells and stuff where you don't want contaminants. So just as a matter of fact, because we autolcave everything, all our tip boxes, autoclave them, they are dried, so that there's no moisture left in it. So it's like a kind of thing, okay,

Nick 13:15
then you dispose of them like how do you just yeah,

P6 Biswa 13:17
so then the use them and dispose of them yeh.

Nick 13:19
It's just like, General waste or?

P6 Biswa 13:21
No, so there are biological waste. So we wouldn't use

Nick 13:27
The racks like empty racks?

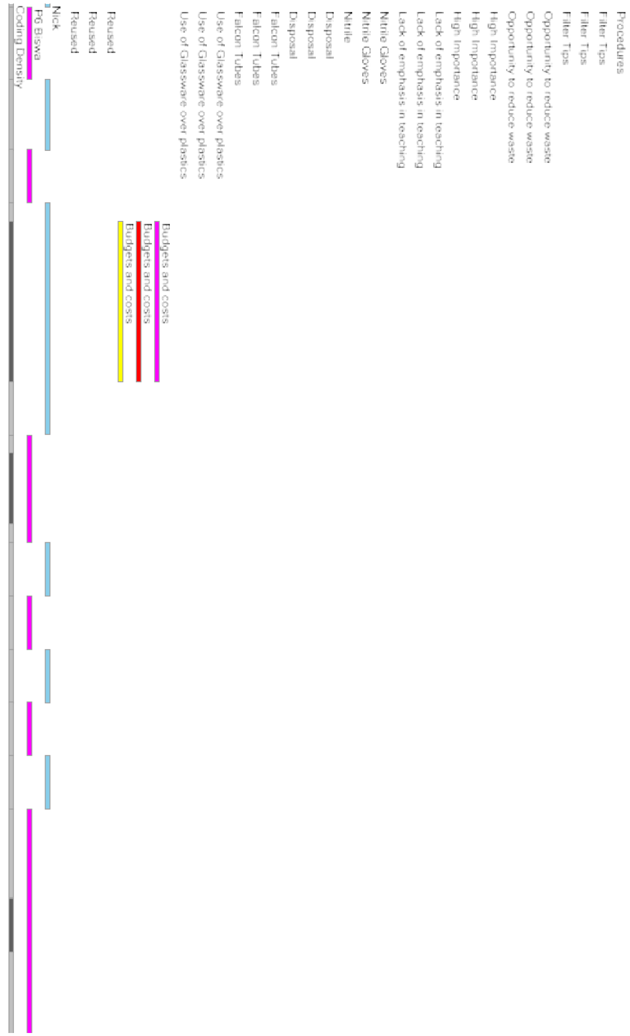
P6 Biswa 13:30
No, so racks are reused.

Oh, so racks always reused?

Yeah. So sometimes what happens is people get, when you need to actually buy them with the tips. They come in a boxes and you just use that. But we usually use the like, lose ones after they come in packs of hundred or 200 and you just fill them. Then the autoclave them and keep reusing the box.

Okay, that's good. Yeah, because I've seen some laboratories who they just always get new tips that come in the boxes.

5 / 8



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I know. maybe a lab. Just gets new tip boxes every time, so much more expensive.

Nick 14:02
They end up with so many racks that they just put into general waste because it's not considered. contaminated.

and then like, there was one company who used to recycle them, but now they need really large quantities. So university I want to store like a black a ton of frickin boxes. Yeah. Do you feel like everyone always knows the best way to dispose of things? Or is there a general just like disposable particles that contaminated or is are things that are not contaminated? Often disposed of in contaminated? Like,

P6 Biswa 14:41
like, honestly people don't. Half of the people in the lab don't even know which waste goes into which one so they go and ask the postdocs "Am I doing the right thing, is going into the right bin?" So I... and it's not they are not being taught when you join the lab. The first thing they go through in the induction is where do you have to dispose what waste but they just do it for the sake of doing it, so you can always reach a score of 80% if you just keep redoing them, so they remember the answers do it. And then they forget what and they don't follow the protocol in the lab.

Nick 15:11
How many different categories of waste do you guys sort into?

P6 Biswa 15:13
we have, like

Nick 15:15
because you deal with...

P6 Biswa 15:16
Yeah, so we have biological waste. We have normal waste, biological waste, and there's bacterial waste in the sense that when once you have finished your expression, you take out all your cell pellets, then that medium is actually can still grow bacteria. So you have to bleach them and it goes to a different waistline, it can go to the normal waste.

Nick 15:36
And is that in a container in like a petri dish or how exactly...?

P6 Biswa 15:40
So we've washed them all we transfer them all into one so we have a large beaker in which all that is done like a two liter big beaker. And then you put all of it in that and you add bleach to it one to 10 bleach and then keep it for three hours you know that all the cells would have died and then you just dispose it in the same line, but this has to be done. Okay, yeah, first. Okay.

Nick 16:07
So you've answered this question already, which was about glass and other situations where you can use glass where people don't. Yeah. So you think most people could use class in a lot of situations where they don't.

P6 Biswa 16:17
I mean, if I can why can't others, like same thing he is doing or she is doing that I'm doing.

Nick 16:22
Is there enough glass equipment to go around?

P6 Biswa 16:24
We have a glass center.

Oh, yeah.

That they just give you.

Is it free?

It's not free. It's a very nominal cost though.

Okay.

And you can just go back and if you have a broken piece, they'll fix it for you.

Nick 16:36
Okay. Is it a quick process? Can you just that day walk down there and grab it or fix it?

P6 Biswa 16:40
yeh it's pretty quick Well, I have given them three because it wants to be

and they gave it the next day. It's pretty good. Easy.

Nick 16:51
Okay, in your research, what do you think is the largest sustainability issue? Whether it's plastic or not? Like what other system issues.

P6 Biswa 17:01
I would say gloves.

gloves

Yeh, gloves.

Like you can't reuse them obviously.

Nick 17:05
do you usually use nitrile or latex?

P6 Biswa 17:07
Nitrile and we try to reuse them. There's some people who throw like there was a guy who graduated, he used to use three, four gloves every day. And I try to use the same glove like for three, four days or less. I know that it's

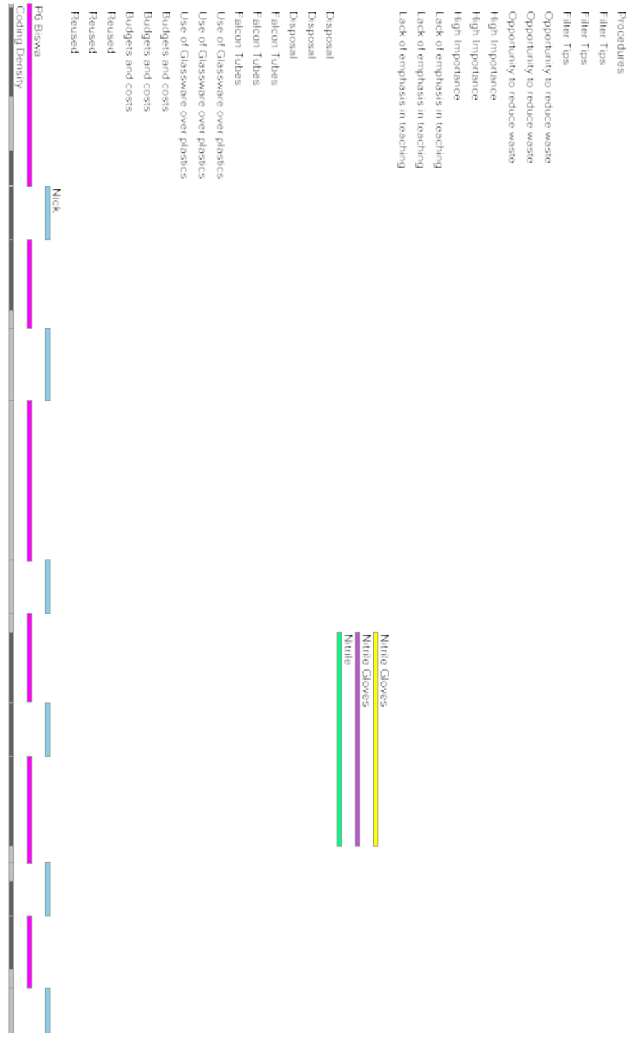
Nick 17:18
Three or four days?

P6 Biswa 17:19
Yeah, I mean, okay, like, if I've done something like really, like with a lot of acid work a lot of bio contaminant work, I just dispose it that in there, but if you have just been purifying normal, like just HPLC or maybe just mundane stuff and making a sample can be reused. Yeah. And at the at the max, you just put some spray some ethanol and then use them after a certain point you can't.

Nick 17:41
Okay. So there's no sterilize process like do you. oh so you spray some ethanol on you.

P6 Biswa 17:46
Yeah and you do it all the time. Even when you get a new gloves. It is obviously sterile, but you still don't take a chance we always spray ethanol.

Nick 17:56



Is there any process like do you like with some of the containers? himself. Do you sterilize it before disposal? Or do you just to bin it in contaminated waste or biological waste?

P6 Biswa 18:06
mean, since the waste is going to go, and there's going to be a separate incineration process for that, you don't really have to do it. I don't think anybody does that. Just dispose it.

Nick 18:17
Because I know there's Um, there's one company I can get onto it if you if you want, but there's one company that recycles nitrile gloves. Okay, that's good. They require like a sterilization process prior to it, but then they'd grind it down into nitrile powders and reuse it Yeah, yeah. If that's of interest to you, I can I can get the details and forward but yeah, any other things that spring to mind before we wrap up the interview because I obviously don't want to take up too much of your time.

No, that that's fine. I mean, it's more it's it's more to do with the day to day single use plastics I would say we don't really use a lot of other stuff which are, which are like discarded off.

Do you think routine, just like people get into a bad routine. And that's what stops them?

P6 Biswa 19:05
like this guy.

Other 19:05
(Whistles in background)

P6 Biswa 19:08
Plastic user.

Other 19:09
Huh?

P6 Biswa 19:11
Yeah. So it's more to do with how you have been working and see, once you develop a sort of routine work, you maintain the status quo, you don't want to change unless you're like, it works for me, because.

Nick 19:23
it's consistent.

P6 Biswa 19:23
It's consistent.

Nick 19:24
So you want to get consistent results. I see. Okay, cool. Cool. Thank you very much.

12.4 APPENDIX 2 | INTERVIEW CODING DIAGRAMS

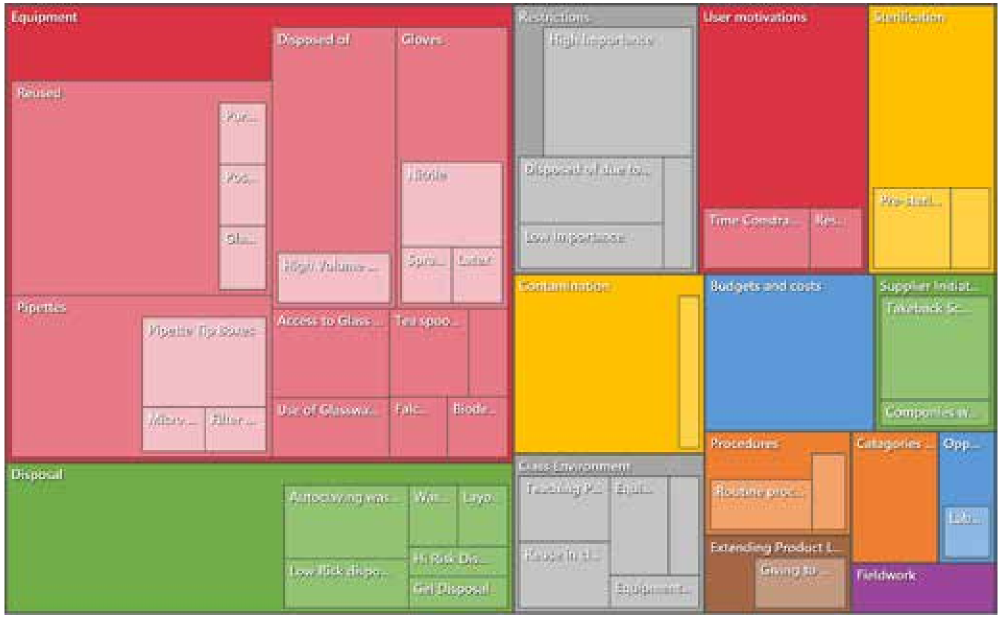


Figure: Axial coding diagram (created with NVivo)
Author's own (2020).

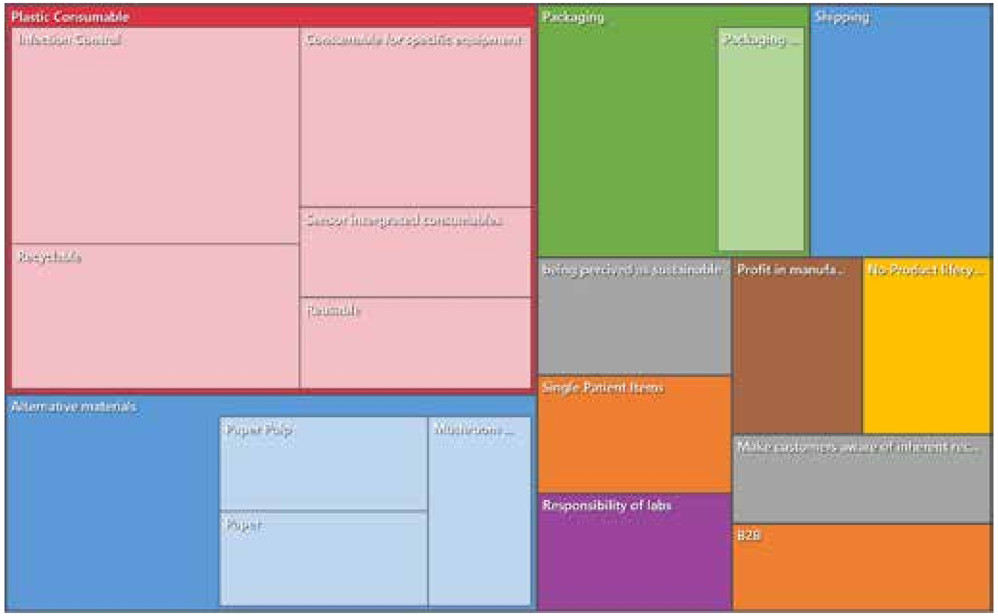


Figure: Open coding diagram for only manufacturing interviewee (created with NVivo)
Author's own (2020).

12.5 APPENDIX 2 | INTERVIEW CODING NODE STRUCTURES

AXIAL CODING

Axial Coding of all interviews

Name	Files	References	Created On	Created By	Modified On	Modified By
Being perceived as sustainable	1	1	16/06/2020 9:03 AM	NS	16/06/2020 10:36 AM	NS
Supplier Initiatives	0	0	16/06/2020 9:04 AM	NS	9/06/2020 12:52 PM	NS
Companies wanting to be sustainable	1	1	16/06/2020 9:04 AM	NS	9/06/2020 12:46 PM	NS
Takeback Scheme	2	4	16/06/2020 9:04 AM	NS	6/06/2020 7:56 PM	NS
Budget Sustainability	0	0	16/06/2020 9:06 AM	NS	16/06/2020 9:11 AM	NS
Alternative materials	1	2	16/06/2020 9:03 AM	NS	16/06/2020 9:18 AM	NS
Mushroom Pulp	1	1	16/06/2020 9:00 AM	NS	16/06/2020 9:21 AM	NS
Paper	1	1	16/06/2020 9:03 AM	NS	16/06/2020 9:21 AM	NS
Paper Pulp	1	1	16/06/2020 9:03 AM	NS	16/06/2020 9:21 AM	NS
Biodegradable	1	1	16/06/2020 9:04 AM	NS	16/06/2020 9:18 AM	NS
Budgets and costs	4	7	16/06/2020 9:04 AM	NS	16/06/2020 9:11 AM	NS
Contamination	3	8	16/06/2020 9:04 AM	NS	16/06/2020 9:18 AM	NS
Experiments ruined due to contamination	1	2	16/06/2020 9:04 AM	NS	16/06/2020 9:18 AM	NS
Time Constraints	2	2	16/06/2020 9:04 AM	NS	8/06/2020 9:50 PM	NS
Using sterilised products	4	6	16/06/2020 9:04 AM	NS	16/06/2020 9:26 AM	NS
Autoclaving products before use	1	1	16/06/2020 9:04 AM	NS	3/06/2020 9:50 PM	NS
Pre sterilised products	1	2	16/06/2020 9:04 AM	NS	8/06/2020 8:13 PM	NS
Business needs and profits	0	0	16/06/2020 10:01 AM	NS	16/06/2020 10:04 AM	NS
B2B	1	1	16/06/2020 9:03 AM	NS	9/06/2020 1:24 AM	NS
Packaging	1	2	16/06/2020 9:03 AM	NS	9/06/2020 1:23 AM	NS
Profit in manufacture of consumables over machines	1	1	16/06/2020 9:03 AM	NS	9/06/2020 1:27 AM	NS
Sensor intergrated consumables	1	1	16/06/2020 9:03 AM	NS	9/06/2020 1:26 AM	NS
Shipping	1	2	16/06/2020 9:03 AM	NS	9/06/2020 1:23 AM	NS
Existing Sustainability Initiatives	0	0	16/06/2020 10:50 AM	NS	16/06/2020 10:50 AM	NS
Access to Glass equipment	1	3	16/06/2020 9:04 AM	NS	8/06/2020 10:02 PM	NS
Fieldwork	1	2	16/06/2020 9:04 AM	NS	16/06/2020 9:53 AM	NS
Recyclable	1	2	16/06/2020 9:03 AM	NS	9/06/2020 1:21 AM	NS
Use of Glassware over plastics	1	2	16/06/2020 9:04 AM	NS	16/06/2020 9:53 AM	NS
Waste Allowance	1	1	16/06/2020 9:04 AM	NS	8/06/2020 7:11 PM	NS
Regulations from a health and safety concern	0	0	16/06/2020 9:24 AM	NS	16/06/2020 9:24 AM	NS
Autoclaving waste before disposal	1	3	16/06/2020 9:04 AM	NS	16/06/2020 9:25 AM	NS
Categories of lab waste	1	3	16/06/2020 9:04 AM	NS	7/06/2020 3:33 PM	NS
Consumable for specific equipment	1	2	16/06/2020 9:03 AM	NS	9/06/2020 1:28 AM	NS
Disposal	6	11	16/06/2020 9:04 AM	NS	9/06/2020 12:46 PM	NS
Gel Disposal	1	1	16/06/2020 9:04 AM	NS	8/06/2020 8:19 PM	NS
Hi Risk Disposal Method	1	1	16/06/2020 9:04 AM	NS	16/06/2020 9:25 AM	NS
Infection Control	1	3	16/06/2020 9:03 AM	NS	9/06/2020 1:21 AM	NS
Low Risk disposal method	2	2	16/06/2020 9:04 AM	NS	16/06/2020 9:25 AM	NS

Name	Files	References	Created On	Created By	Modified On	Modified By
Procedures	1	1	16/06/2020 9:04 AM	NS	8/06/2020 9:39 PM	NS
Process Rules the Equipment Material	1	1	16/06/2020 9:04 AM	NS	8/06/2020 3:08 PM	NS
Responsibility of labs	1	1	16/06/2020 9:03 AM	NS	16/06/2020 9:25 AM	NS
Restrictions	1	1	16/06/2020 9:04 AM	NS	16/06/2020 9:23 AM	NS
Disposed of due to council regulations	1	3	16/06/2020 9:04 AM	NS	16/06/2020 9:23 AM	NS
Handeling of waste (Cleaners)	1	1	16/06/2020 9:04 AM	NS	16/06/2020 9:25 AM	NS
High Importance	2	8	16/06/2020 9:04 AM	NS	16/06/2020 9:25 AM	NS
Low Importance	1	2	16/06/2020 9:04 AM	NS	16/06/2020 9:25 AM	NS
Single Patient Items	1	1	16/06/2020 9:03 AM	NS	16/06/2020 9:25 AM	NS
Single Patient use Items	1	1	16/06/2020 9:03 AM	NS	16/06/2020 10:03 AM	NS
Reusing items that are designed as disposables	3	0	16/06/2020 10:45 AM	NS	16/06/2020 10:46 AM	NS
Falcon Tubes	1	1	16/06/2020 9:04 AM	NS	8/06/2020 9:56 PM	NS
Spray with Ethanol	1	1	16/06/2020 9:04 AM	NS	8/06/2020 10:09 PM	NS
Routines and habits relationship to the products use	3	0	16/06/2020 10:35 AM	NS	16/06/2020 10:35 AM	NS
Equipment	2	4	16/06/2020 9:04 AM	NS	8/06/2020 7:07 PM	NS
Disposed of	3	8	16/06/2020 9:04 AM	NS	8/06/2020 8:18 PM	NS
High Volume Disposal	2	2	16/06/2020 9:04 AM	NS	8/06/2020 10:11 PM	NS
Gloves	2	4	16/06/2020 9:04 AM	NS	8/06/2020 10:07 PM	NS
Latex Gloves	1	1	16/06/2020 9:04 AM	NS	16/06/2020 10:48 AM	NS
Nitrile Gloves	3	3	16/06/2020 9:04 AM	NS	16/06/2020 10:48 AM	NS
Materials	0	0	16/06/2020 9:04 AM	NS	7/06/2020 5:38 PM	NS
Pipettes	3	6	16/06/2020 9:04 AM	NS	8/06/2020 10:13 PM	NS
Filter Tips	1	1	16/06/2020 9:04 AM	NS	8/06/2020 9:54 PM	NS
Micro pipette tips	1	1	16/06/2020 9:04 AM	NS	8/06/2020 10:07 PM	NS
Reused	3	13	16/06/2020 9:04 AM	NS	15/06/2020 5:59 PM	NS
Glassware usage	1	1	16/06/2020 9:04 AM	NS	15/06/2020 5:57 PM	NS
Purchasing own equipments for classes	1	1	16/06/2020 9:04 AM	NS	15/06/2020 5:58 PM	NS
Tea spoons	1	2	16/06/2020 9:04 AM	NS	8/06/2020 10:17 PM	NS
Sustainability opportunities	0	0	16/06/2020 9:51 AM	NS	16/06/2020 10:00 AM	NS
Extending Product Life of Machinery	1	1	16/06/2020 9:04 AM	NS	9/06/2020 12:51 PM	NS
Giving to others	1	2	16/06/2020 9:04 AM	NS	8/06/2020 8:02 PM	NS
Make customers aware of inherent recyclability	1	1	16/06/2020 9:03 AM	NS	16/06/2020 9:53 AM	NS
No Product lifecycle information	1	1	16/06/2020 9:03 AM	NS	9/06/2020 1:20 AM	NS
Opportunity to reduce waste	1	1	16/06/2020 9:04 AM	NS	16/06/2020 9:53 AM	NS
Labs that can avoid plastic waste	1	1	16/06/2020 9:04 AM	NS	8/06/2020 9:46 PM	NS
Pipette Tip Boxes	2	4	16/06/2020 9:04 AM	NS	8/06/2020 9:59 PM	NS
Possible reusable items	1	1	16/06/2020 9:04 AM	NS	15/06/2020 5:59 PM	NS
Researcher discretion	1	1	16/06/2020 9:04 AM	NS	8/06/2020 9:48 PM	NS
Routine procedures	2	3	16/06/2020 9:04 AM	NS	16/06/2020 10:48 AM	NS
Wooden Pallets	1	1	16/06/2020 9:04 AM	NS	8/06/2020 7:13 PM	NS
Teaching undergraduates and students - High quantity and the same or similar tasks	0	0	16/06/2020 9:19 AM	NS	16/06/2020 9:20 AM	NS
Class Environment	0	0	16/06/2020 9:04 AM	NS	16/06/2020 9:21 AM	NS
Equipment for undergrads	1	2	16/06/2020 9:04 AM	NS	16/06/2020 9:21 AM	NS
Equipment supplied by others	1	1	16/06/2020 9:04 AM	NS	16/06/2020 9:21 AM	NS
Lack of emphasis in teaching	1	1	16/06/2020 9:04 AM	NS	16/06/2020 9:21 AM	NS
Reuse in class settings	1	2	16/06/2020 9:04 AM	NS	16/06/2020 9:21 AM	NS
Teaching Pracs	1	2	16/06/2020 9:04 AM	NS	16/06/2020 9:21 AM	NS
Layout of waste disposal	1	1	16/06/2020 9:04 AM	NS	7/06/2020 5:32 PM	NS
User motivations	5	9	16/06/2020 9:04 AM	NS	8/06/2020 10:12 PM	NS

OPEN CODING LAB USER INTERVIEWS

Laboratory Users - Interviews

Name	Files	References	Created On	Created By	Modified On	Modified By
Budgets and costs	4	7	7/06/2020 5:49 PM	NS	8/06/2020 8:57 PM	NS
Categories of lab waste	1	3	7/06/2020 5:26 PM	NS	7/06/2020 5:33 PM	NS
Class Environment	0	0	8/06/2020 12:49 PM	NS	8/06/2020 12:49 PM	NS
Equipment for undergrads	1	2	8/06/2020 10:09 PM	NS	8/06/2020 10:10 PM	NS
Equipment supplied by others	1	1	7/06/2020 5:26 PM	NS	7/06/2020 5:26 PM	NS
Lack of emphasis in teaching	1	1	8/06/2020 9:48 PM	NS	8/06/2020 9:48 PM	NS
Reuse in class settings	1	2	7/06/2020 5:43 PM	NS	7/06/2020 5:44 PM	NS
Teaching Pracs	1	2	8/06/2020 8:11 PM	NS	8/06/2020 8:11 PM	NS
Contamination	3	8	7/06/2020 5:08 PM	NS	8/06/2020 10:13 PM	NS
Experiments ruined due to contamination	1	1	7/06/2020 6:14 PM	NS	7/06/2020 6:14 PM	NS
Disposal	6	11	7/06/2020 4:23 PM	NS	8/06/2020 12:46 PM	NS
Autoclaving waste before disposal	1	3	7/06/2020 5:52 PM	NS	7/06/2020 5:53 PM	NS
Gel Disposal	1	1	8/06/2020 8:19 PM	NS	8/06/2020 8:19 PM	NS
Hi Risk Disposal Method	1	1	8/06/2020 7:08 PM	NS	8/06/2020 7:09 PM	NS
Layout of waste disposal	1	1	7/06/2020 3:31 PM	NS	7/06/2020 3:32 PM	NS
Low Risk disposal method	2	2	8/06/2020 7:08 PM	NS	8/06/2020 10:04 PM	NS
Waste Allowance	1	1	8/06/2020 7:11 PM	NS	8/06/2020 7:11 PM	NS
Equipment	2	4	7/06/2020 4:22 PM	NS	8/06/2020 7:07 PM	NS
Access to Glass equipment	1	3	8/06/2020 10:01 PM	NS	8/06/2020 10:02 PM	NS
Biodegradable	1	1	8/06/2020 9:09 PM	NS	9/06/2020 12:53 PM	NS
Disposed of	3	8	7/06/2020 5:13 PM	NS	8/06/2020 8:18 PM	NS
High Volume Disposal	2	2	7/06/2020 5:26 PM	NS	8/06/2020 10:11 PM	NS
Falcon Tubes	1	1	8/06/2020 8:55 PM	NS	8/06/2020 8:56 PM	NS
Gloves	2	4	8/06/2020 8:54 PM	NS	8/06/2020 10:07 PM	NS
Latex	1	1	8/06/2020 9:04 PM	NS	8/06/2020 9:04 PM	NS
Nitrile	3	3	8/06/2020 9:04 PM	NS	8/06/2020 10:11 PM	NS
Spray with Ethanol	1	1	8/06/2020 10:03 PM	NS	8/06/2020 10:03 PM	NS
Materials	3	9	7/06/2020 5:30 PM	NS	7/06/2020 5:30 PM	NS
Pipettes	3	6	7/06/2020 5:53 PM	NS	8/06/2020 10:15 PM	NS
Filter Tips	1	1	8/06/2020 8:54 PM	NS	8/06/2020 8:54 PM	NS
Micro pipette tips	1	1	8/06/2020 10:07 PM	NS	8/06/2020 10:07 PM	NS
Pipette Tip Boxes	2	4	8/06/2020 7:12 PM	NS	8/06/2020 9:03 PM	NS
Reused	3	13	7/06/2020 5:11 PM	NS	15/06/2020 5:09 PM	NS
Glassware usage	1	1	15/06/2020 5:37 PM	NS	15/06/2020 5:37 PM	NS
Possible reusable items	1	1	15/06/2020 5:38 PM	NS	15/06/2020 5:39 PM	NS
Purchasing own equipment for classes	1	1	15/06/2020 5:55 PM	NS	15/06/2020 5:56 PM	NS
Tea spoons	1	2	8/06/2020 10:07 PM	NS	8/06/2020 10:11 PM	NS
Use of Glassware over plastics	1	2	8/06/2020 9:42 PM	NS	8/06/2020 9:43 PM	NS
Wooden Pallets	1	1	8/06/2020 7:15 PM	NS	8/06/2020 7:15 PM	NS
Extending Product Life of Machinery	1	1	8/06/2020 7:59 PM	NS	8/06/2020 12:01 PM	NS
Giving to others	1	2	8/06/2020 8:09 PM	NS	8/06/2020 8:02 PM	NS
Fieldwork	1	2	7/06/2020 5:34 PM	NS	7/06/2020 5:43 PM	NS
Opportunity to reduce waste	1	1	8/06/2020 9:53 PM	NS	8/06/2020 9:53 PM	NS
Labs that can avoid plastic waste	1	1	8/06/2020 9:46 PM	NS	8/06/2020 9:46 PM	NS
Procedures	1	1	8/06/2020 8:59 PM	NS	8/06/2020 8:58 PM	NS
Process Runs the Equipment Material	1	1	8/06/2020 5:06 PM	NS	8/06/2020 5:06 PM	NS
Routine procedures	1	2	8/06/2020 8:21 PM	NS	8/06/2020 10:03 PM	NS
Restrictions	1	1	7/06/2020 5:07 PM	NS	8/06/2020 8:07 PM	NS
Disposed of due to council regulations	1	3	8/06/2020 7:17 PM	NS	8/06/2020 7:52 PM	NS
Handling of waste (General)	1	1	8/06/2020 8:12 PM	NS	8/06/2020 8:12 PM	NS
High Importance	2	6	7/06/2020 5:08 PM	NS	8/06/2020 9:40 PM	NS
Low Importance	1	2	7/06/2020 5:08 PM	NS	7/06/2020 5:25 PM	NS
Sterilisation	4	8	7/06/2020 5:10 PM	NS	8/06/2020 10:13 PM	NS
Autoclaving products before use	1	1	8/06/2020 9:58 PM	NS	8/06/2020 9:58 PM	NS
Pre-sterilised products	1	2	8/06/2020 8:10 PM	NS	8/06/2020 8:10 PM	NS
Supplier Initiatives	3	6	8/06/2020 12:52 PM	NS	8/06/2020 12:52 PM	NS
Companies wanting to be sustainable	1	1	8/06/2020 7:56 PM	NS	8/06/2020 12:46 PM	NS
Takeback Scheme	2	4	7/06/2020 3:22 PM	NS	8/06/2020 7:56 PM	NS
User motivations	5	8	7/06/2020 5:48 PM	NS	8/06/2020 10:12 PM	NS
Researcher discretion	1	1	8/06/2020 9:47 PM	NS	8/06/2020 9:48 PM	NS
Time Constraints	2	2	8/06/2020 9:08 PM	NS	8/06/2020 9:50 PM	NS

OPEN CODING MANUFACTURER INTERVIEWS

Manufactur Industry - Interview

Name	Files	References	Created On	Created By	Modified On	Modified By
Alternative materials	1	2	9/06/2020 1:28 AM	NS	9/06/2020 1:29 AM	NS
Mushroom Pulp	1	1	9/06/2020 1:29 AM	NS	9/06/2020 1:29 AM	NS
Paper	1	1	9/06/2020 1:28 AM	NS	9/06/2020 1:28 AM	NS
Paper Pulp	1	1	9/06/2020 1:28 AM	NS	9/06/2020 1:28 AM	NS
B2B	1	1	9/06/2020 1:24 AM	NS	9/06/2020 1:24 AM	NS
Being percived as sustainable	1	1	9/06/2020 1:30 AM	NS	9/06/2020 1:30 AM	NS
Make customers aware of inherent recyclability	1	1	9/06/2020 1:20 AM	NS	9/06/2020 1:20 AM	NS
No Product lifecycle information	1	1	9/06/2020 1:20 AM	NS	9/06/2020 1:20 AM	NS
Packaging	1	2	9/06/2020 1:23 AM	NS	9/06/2020 1:23 AM	NS
Packaging that is a part of the use of the product	1	1	9/06/2020 1:27 AM	NS	9/06/2020 1:27 AM	NS
Plastic Consumable	0	0	9/06/2020 1:25 AM	NS	9/06/2020 1:25 AM	NS
Consumable for specific equipment	1	2	9/06/2020 1:24 AM	NS	9/06/2020 1:26 AM	NS
Infection Control	1	3	9/06/2020 1:18 AM	NS	9/06/2020 1:21 AM	NS
Recyclable	1	2	9/06/2020 1:20 AM	NS	9/06/2020 1:21 AM	NS
Reusable	1	1	9/06/2020 1:18 AM	NS	9/06/2020 1:18 AM	NS
Sensor intergrated consumables	1	1	9/06/2020 1:26 AM	NS	9/06/2020 1:26 AM	NS
Profit in manufacture of consumables over machines	1	1	9/06/2020 1:27 AM	NS	9/06/2020 1:27 AM	NS
Responsibility of labs	1	1	9/06/2020 1:22 AM	NS	9/06/2020 1:22 AM	NS
Shipping	1	2	9/06/2020 1:23 AM	NS	9/06/2020 1:23 AM	NS
Single Patient Items	1	1	9/06/2020 1:19 AM	NS	9/06/2020 1:19 AM	NS

12.6 APPENDIX 3 | QUESTIONNAIRE QUESTIONS

Sustainable Science Questionnaire

Single-use waste in laboratories and sustainable waste management.

1. Please, briefly explain your working experience in laboratories.

2. What age group are you in?

Mark only one oval.

- 18 and under
- 19-30
- 31-45
- 46-60
- 61 and above

3. How much do you agree with the statement? "Sustainable research is second class research"

Mark only one oval.

	1	2	3	4	5	
Strongly disagree						Strongly agree

4. How much do you agree with the statement? "Your research could be conducted in a more sustainable manner"

Mark only one oval.

	1	2	3	4	5	
Strongly disagree						Strongly agree

5. In relation to your previous answer what are the main barriers?

6. Please list the disposable equipment you most commonly use.

7. (In relation to your previous answer) Which of these do you use and dispose of most often?

8. How often do you recycle the plastic laboratory equipment you use?

Mark only one oval.

- Always
- Often
- Sometimes
- Rarely
- Never

9. Based on your own experience, which of the following factors contribute the most to the disposal of plastic lab waste?

Check all that apply.

- Contamination
- Breakages
- Designed to be used once
- Rules / Occupational health and safety
- Habits
- Inability to wash / sterilise
- Other:

10. Do you re-use plastic pipette tips?

Mark only one oval.

- Yes, always
- Often, depending on use
- Sometimes, depending on use
- Rarely, depending on use
- No, Never

11. How many pairs of gloves would you go through in an average day?

Check all that apply.

- 0-1
- 1
- 2
- 3
- 4
- 5
- Other:

12. Do you recycle nitrile gloves?

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Unsure

13. How many categories does your workplace split waste into?

Check all that apply.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- Other: ☐ ____________

14. How much do you agree with the following statement? "To maintain a high standard of results new and disposable equipment should be used over sterilised reusable equipment."

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

15. As a part of this study, a round of interviews will be conducted. If you would like to, please leave your name and contact information and I'll (Nick Sabulis: Primary Researcher) get in contact to organise a time.

12.7 APPENDIX 3 | QUESTIONNAIRE RESULTS SUMMARY (LOCAL)

Sustainable Science Questionnaire

13 responses

Publish analytics

Please, briefly explain your working experience in laboratories.

11 responses

During uni, approx 2 years of classes spend in labs

Dental assistant in dental labs

I am a full time research assisant (1.5yrs) and previously 2 years lab experience (all biological)

Science student

Science (chemistry) student, roughly 180 hours in the lab. Mainly synthesis of products or analytical chemistry (finding how much of each chemical is in a sample of something, etc.)

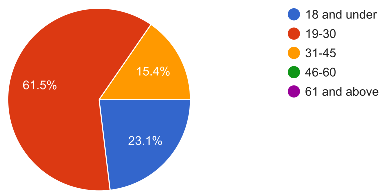
Bachelor of science (chemistry) student

In biomedical science subjects and paramedic science

I do volunteer work in a research lab and I'm studying to be a medical scientist

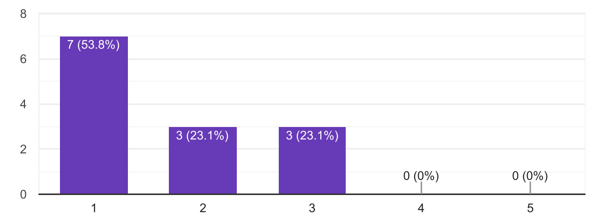
What age group are you in?

13 responses



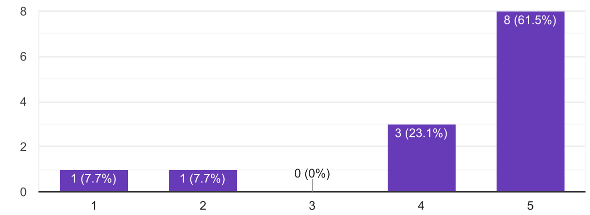
How much do you agree with the statement? "Sustainable research is second class research"

13 responses



How much do you agree with the statement? "Your research could be conducted in a more sustainable manner"

13 responses



In relation to your previous answer what are the main barriers?

13 responses

Test tubes, pipets, gloves, paper wipes, all the single use lab equipment.

Time constraints mean that a lot of single use items are used to make the area clean for the next patient or impression

Cross contamination is a major concern

Contamination, health and safety

Fear of Cross contamination is the main issue. This makes us change gloves regularly, get new pipette tips, new teaspoons for measurement, etc

Use of pipette tips and gloves are the main issue.

So much single use plastic

The fact that everything need to be sterile and that's hard to do if you want to recycle.

Please list the disposable equipment you most commonly use.

13 responses

Baking paper, tissues

Masks, plastic barriers, suction tubes, gloves, floss, applicators, dappin dishes

Micropipette tips, gloves and tubes

Pipette tips, plates

Gloves, plastic teaspoons, micropipette tips

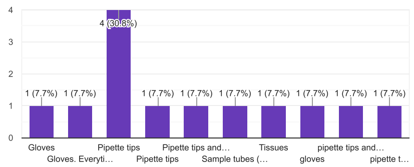
Pipette tips and gloves.

Pipette tips
Gloves
Masks
Plastic wrap

Pipette tips, plastic flasks, media bottles, culture plates and falcon tubes etc

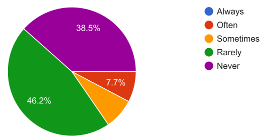
(In relation to your previous answer) Which of these do you use and dispose of most often?

13 responses



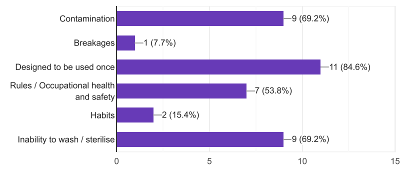
How often do you recycle the plastic laboratory equipment you use?

13 responses



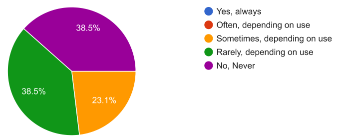
Based on your own experience, which of the following factors contribute the most to the disposal of plastic lab waste?

13 responses



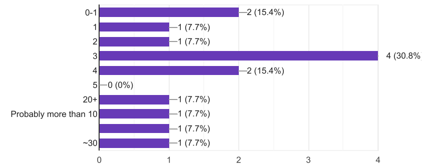
Do you re-use plastic pipette tips?

13 responses



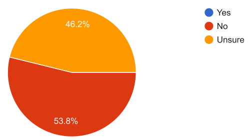
How many pairs of gloves would you go through in an average day?

13 responses



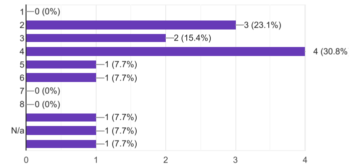
Do you recycle nitrile gloves?

13 responses



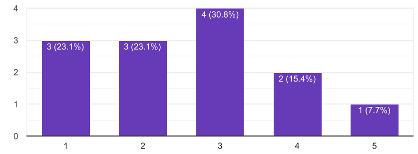
How many categories does your workplace split waste into?

13 responses



How much do you agree with the following statement? "To maintain a high standard of results new and disposable equipment should be used over sterilised reusable equipment."

13 responses



12.8 APPENDIX 3 | QUESTIONNAIRE RESULTS SUMMARY (INTERNATIONAL)

Sustainable Science Questionnaire

11 responses

Publish analytics

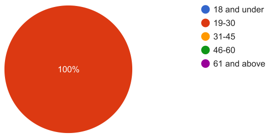
Please, briefly explain your working experience in laboratories.

9 responses

- I have 5 year experience working in chemistry lab - 4 as apprentice, 1 as employee
- My dog is a lab and i give him lots of pets so i think that counts
- PhD Candidate in Biochemistry
- Class, research
- Marine invertebrate lab tech
- Worked in: 3 university experimental physics laboratories, 1 industrial battery research lab
- I collect the field samples (wildlife blood samples & skin swabs) that are sent to laboratories for testing
- Biotechnology Master, worked in laboratories for my studies. In total over 2 years of pure lab work.

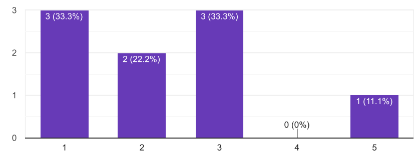
What age group are you in?

9 responses



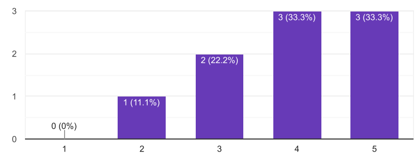
How much do you agree with the statement? "Sustainable research is second class research"

9 responses



How much do you agree with the statement? "Your research could be conducted in a more sustainable manner"

9 responses



In relation to your previous answer what are the main barriers?

8 responses

- Many of the utensils that I use are intended for one time use only. Changing those things to more sustainable alternatives is difficult (need to be sterile/ not able to break when centrifuged)
- There are none
- The impossibility of reusable gloves
- We don't use too much plastic, but what we do use is food packaging
- Time and money. The main barrier is time, because returning materials to a non-contaminated state is very costly in time, and time is the main resource that most labs try to preserve.
- Reusable items also have a higher upfront cost compared to single use items.
- Safety items such as gloves and masks are often best as single-use because user error can result in experimenter injury and exposure to toxins. This is especially important for young researchers who are less experienced and less aware of the

Please list the disposable equipment you most commonly use.

9 responses

- Pipette tips, eppendorf tubes, pipettes (glass or plastic), hplc/gc vials, gloves
- Forks
- Tips, gloves, tubes, TC plates
- Gloves, pipettes
- Food packaging for invertebrates (fish and brine shrimp). Also, cleaning brushes.
- Gloves, rubber sample holders, kimwipes, circular papers for measuring samples, foil, electrolyte paper, paper towels, water, other cleaning solvents.
- Vials, needles, gloves, swabs
- Pippet tips size 10 - 500, falcon tubes, gloves.
- Pipette tips, gloves, pipettes

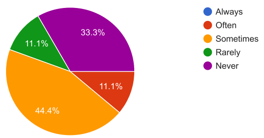
(In relation to your previous answer) Which of these do you use and dispose of most often?

9 responses

- All of them get used roughly the same amount
- White ones
- Tips
- Pipettes
- Food packaging
- Nitrile gloves
- Vials, needles, gloves, swabs
- Pippet tips 200
- Pipette tips

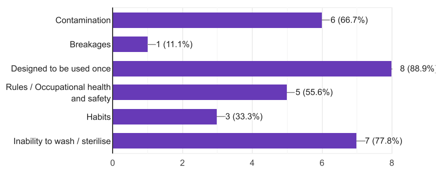
How often do you recycle the plastic laboratory equipment you use?

9 responses



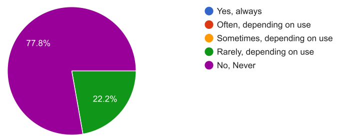
Based on your own experience, which of the following factors contribute the most to the disposal of plastic lab waste?

9 responses



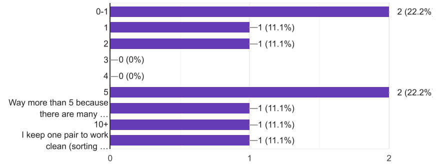
Do you re-use plastic pipette tips?

9 responses



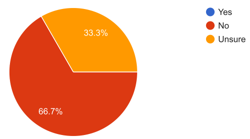
How many pairs of gloves would you go through in an average day?

9 responses



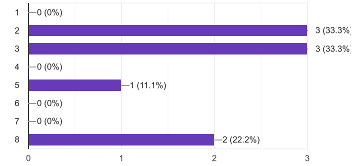
Do you recycle nitrile gloves?

9 responses



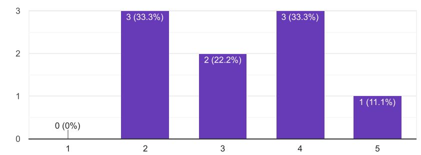
How many categories does your workplace split waste into?

9 responses

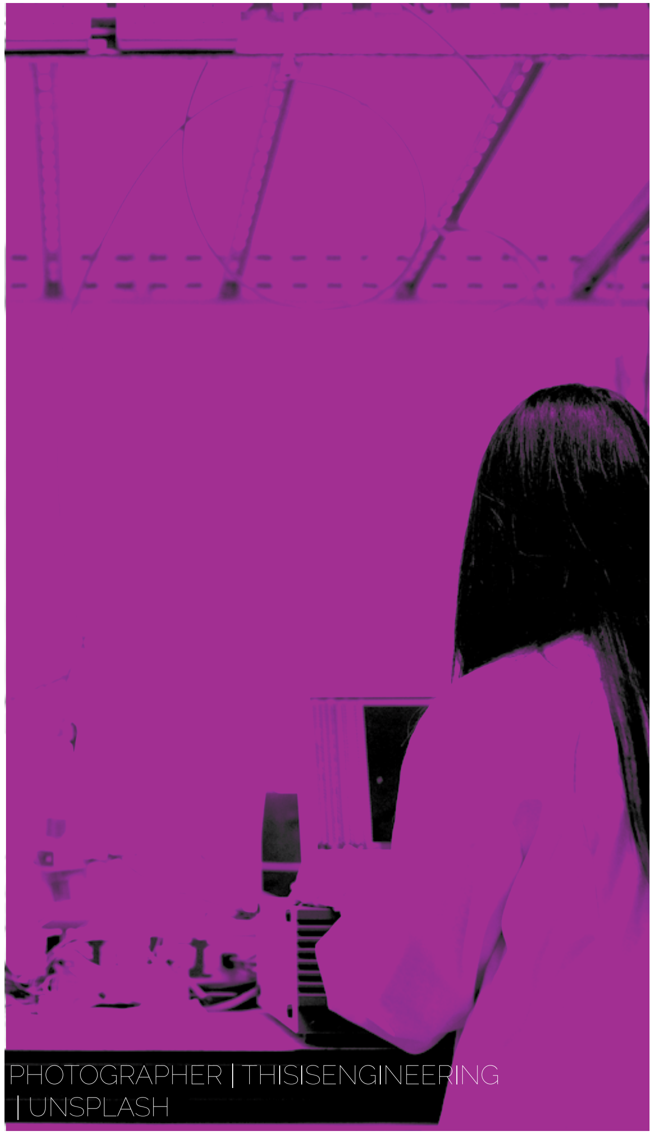


How much do you agree with the following statement? "To maintain a high standard of results new and disposable equipment should be used over sterilised reusable equipment."

9 responses



12.9 APPENDIX 4 | RESEARCH QUESTIONS



REVISED QUESTIONS

Research Question 1

- *How do laboratory users interact with different plastic lab equipment to make it unlikely to be reused or recycled?*

Research Question 2

- *How do sustainable research methods effect quality of research* and reaching *high standards?*

VARIABLES TO ANSWER

Independent Variables:

- *Plastic Laboratory Equipment (materials, shapes, volumes, weights, type of equipment)*
- *High Standards (accuracy, consistency, repeatable)*

Dependent Variables:

- *Interaction (use of equipment, experiments, contamination)*
- *Sustainable Research Methods (reusable equipment, recycled materials, biodegradable materials, reduced material waste)*