PLASTIC IN PRACTICE

AN EMPIRICAL APPROACH TO 3D PRINTED UPCYCLING IN NEW ZEALAND SCHOOLS

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Plastic in practice:
An empirical approach to 3D printed upcycling in New Zealand schools

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ABSTRACT

Plastic has become an integral material in our society due to the broad range of applications it can be used for, however, it is having a detrimental effect on our environment. In addition to more efficient waste management systems, a cultural shift through education is fundamental for more effective management of plastic waste. Although the New Zealand National Curriculum currently teaches students about sustainability, the method of teaching remains conventional and does not explore the empirical, tactile learning opportunities that 3D printing provides. This research portfolio proposes the importance of an education programme which focuses on plastic waste, upcycling and 3D printing in New Zealand schools. It explores how tangible learning can engage students more effectively with topics such as sustainability. Through collaborating with students and teachers, participatory research methods have been employed in order to form a foundation for an education programme focused on 3D printed upcycling within New Zealand. The final output of this research consists of an education programme proposal, as well as a series of projects which could be integrated into the programme.

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MOTIVATION

During my undergraduate study, the area of design I was most interested in was sustainable design, and specifically designing for children. After assisting with university research focused on the upcycling of plastic waste into filament for 3D printing, I was also inspired to explore how upcycling could be applied to benefit New Zealand's current waste management systems. This led me to the idea of designing an educational 3D printed upcycling programme that could be integrated within schools across the country.

Fonterra is New Zealand's largest exporter of dairy products, playing an important role in the national economy, but at the same time contributing towards a substantial amount of single-use plastic being used and disposed of in New Zealand. Before this research took place, Fonterra reached out to Victoria University School of Design to express an interest in developing sustainable solutions to their plastic waste problem. After a meeting with Fonterra's Environmental and Sustainability Advisor, an educational focus was agreed upon as the best approach for a research portfolio focused on the upcycling of plastic waste as it aligned with their future focus regarding sustainability. For this research, Fonterra supplied an abundance of their plastic waste products to carry out material experimentation and develop design concepts. This partnership motivated me through being provided the opportunity to develop an educational school programme that incorporates sustainable learning and systems that will work to inspire leading New Zealand companies to create systematic improvements that support future generations.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Plastic has become an integral material in our society due to its wide range of applications, however, our current dependence on it creates several environmental problems. Plastic uses oil and gas, non-renewable resources, as a feedstock for production and its durability means that a large amount of it is accumulating as debris in landfills or natural habitats (Hopewell, Dvorak & Kosier, 2009). The global production of plastic has grown by 500% in the last 30 years, and is expected to continue to grow (Lebreton, Greer & Borrero, 2012). Due to the lack of ways to sufficiently deal with the increasing plastic waste generated globally, finding a solution has become a pressing issue in today's society (Lebreton, et al., 2012).

The majority of plastic produced each year is used to make disposable items, such as packaging or other short-lived products that are thrown away within a year of manufacture (Hopewell, et al., 2009). In New Zealand, there is a strong focus on the production of dairy products, as they play a significant role in the country's economy (Workman, 2020). With most dairy packaging being made from plastic, there is a strong need and interest within New Zealand to find more sustainable solutions for how dairy packaging is recycled and managed.

Additive manufacturing techniques, such as 3D printing, is well known as an alternative method of manufacturing, but also has the capability to upcycle plastic into more valuable objects (Huang, Liu, Mokasdar & Hou, 2013; Lipson & Wixson, 2012). Upcycling is regarded as one of the most sustainable methods of production as it has a low material cost and reduces the demand for new products (Herman, Sbarcea, & Panagopoulos, 2018). It also provides opportunities to engage people through the making process, as designs can be customised through 3D modelling software.

Within education, 3D printing technologies can engage students in the upcycling process, enabling collaboration and providing a tangible way for students to learn about sustainability. The New Zealand Curriculum has a focus on education for sustainability, aiming to educate students about the importance of sustaining our environment (Ministry of Education, 2020). Introducing plastic waste upcycling from an early age can empower students with awareness of the impact plastic waste has on our environment, and encourage innovative solutions (Taylor, Quinn & Eames, 2015). Through educating and collaborating with students, this research investigates how integrating participatory, tangible methods of education has the potential to engage students with topics such as sustainability: a fundamental step towards reducing the issue of plastic waste. This prompts the research question:

How can 3D printing be combined with plastic waste processing in the context of New Zealand schools to demonstrate sustainable systems in practice to students?

1.1

RESEARCH PORTFOLIO CHAPTER OVERVIEW

This thesis is structured in chronological order, narrating the iterative intent of the research and reflecting on my process and story as a designer.

Chapter 02 - Background Research
This chapter explores the research areas of plastic, waste management, additive manufacturing, upcycling, sustainability and education. Reflecting on important literature, precedents and background information, this chapter provides a contextual overview of the research topic and will be used as a foundation to inform subsequent research.

Chapter 03 - Methodology
This chapter outlines the aims and objectives of the research, and how they will be addressed in order to answer the research question. It provides an in-depth overview of the research methods which will be applied at each stage of the process.

Chapter 04 - Material Experimentation
Consisting of materials research and experimentation, this chapter investigates how 3D printing technologies can be used to upcycle and repurpose single-use plastic waste. A variety of plastic types are explored, analysing which would be most suitable for the context of education. As well as this, it provides an informed understanding of the process of upcycling single-use plastic into filament for 3D printing for design development.

Chapter 05 - Participatory Research

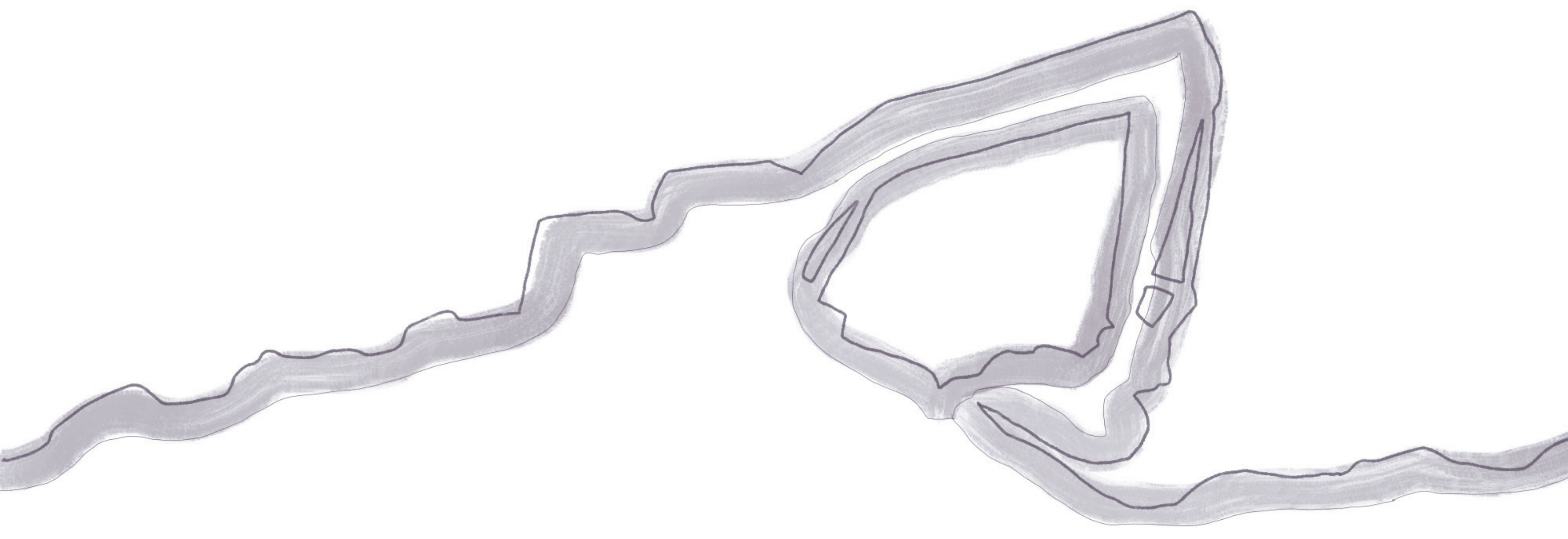
This chapter consists of qualitative research, collaborating with three schools across New Zealand as well as a range of teachers. Participatory methods including observation, focus groups, and cultural probes were employed at this stage of the research, providing a more informed understanding of what students and teachers would want from an education programme focused on 3D printed upcycling.

Chapter 06 - Program Proposal

Based on research findings from both the material experimentation and participatory research stages, a proposal for an education programme focused on 3D printed upcycling in New Zealand has been outlined in this chapter. Project concepts for the programme have been developed based on what would be engaging for students as well as achievable for teachers and schools.

Chapter 07 - Discussion & Conclusion

Reflecting upon the research process, findings and design output of the thesis, this chapter discusses the potential of the proposed education school programme being used as a tool for sustainable systems in practice to students. As well as this, it analyses the impact and limitations of this research, and the potential for future research within this area.



02

BACKGROUND RESEARCH

OVERVIEW

The purpose of this background research was to explore the research fields of plastic, waste management, additive manufacturing, upcycling, sustainability and education. Findings from this research were used to inspire and develop the methodology and inform further stages of the research process.

2.1

PLASTIC

INVENTION OF PLASTIC

The first invention of plastic was in 1869, in response to a firm in New York offering $10,000 to anyone that can provide a substitute for ivory (Seidensticker, 2006). Since its first invention, the demand for plastic has grown exponentially, diverging significantly from its original purpose. Plastic has become an integral material in our society due to its substantial benefits in terms of its low weight, durability and lower cost relative to many other material types (Andrady & Neal, 2009; Thompson, Swan, Moore & vom Saal, 2009). Globally our production of plastic has increased by 500% over the last 30 years and it is expected to continue to grow to 850 million tons per year by 2050 (Lebreton et al., 2012). Over the last few decades, plastic has been a key enabler of innovation and has contributed to the development and progress of society (Hopewell et al., 2009). This is due to it being a versatile material that can be used in a wide range of applications, from simple single-use packaging to high-tech durable industrial applications (Milios, Davani, & Yu, 2018).

CONSEQUENCES OF PLASTIC

Despite the multiple benefits of plastic use, the material raises several environmental concerns throughout its life cycle (Milios et al., 2018). The raw materials on which manufactured plastic types are based are primarily petrochemicals - derived from fossil fuels (Olah, Goeppert, & Surya, 2009). These natural resources are finite and impact the environment negatively throughout the extraction, production and utilisation processes (World Economic Forum, 2016). This highlights the need to recycle the plastic which already exists, rather than continuing to negatively impact the environment through the production of new plastic.

Speight (2014) argues that a future without plastic is hard to imagine, as our current way of living has been so heavily impacted by its discovery and rapid adoption. In a 2017 study, Tyree & Morrison (2017) found that on a global level, there has been more plastic produced in the last 10 years than in the entirety of the last century. Consequently, an excessive amount of waste is produced and the overwhelming majority of it ends up in landfill or contaminating the environment (Brooks, Wang & Jambeck, 2018). Li, Tse & Fok (2016) explain that due to the chemical structure of plastic, its degradation is a very slow process and can take over a century. While degrading, the plastic is fragmented into smaller pieces known as macro- and microplastic. Currently, there are approximately 150 million tonnes of mishandled plastic waste that has washed into the world's oceans, rivers, lakes. Furthermore, every year 8 million additional tonnes of plastic ends up in the marine environment (Tyree & Morrison, 2017). This evidence highlights the increasing amount of plastic being disposed of within our current global environment, impacting wildlife and polluting environments, waterways and oceans.

PLASTIC IN NEW ZEALAND

As a nation, New Zealand relies on its reputation for being a clean, green country. In a 2013 study, Tourism New Zealand claimed that the '100% Pure' marketing campaign has increased the number of tourists visiting New Zealand by 50% (Morgan, 2013). However, according to an Organisation for Economic Co-operation and Development (OECD) report from 2017, New Zealand generates more waste per capita as compared to other OECD countries (Perrot & Subiantoro, 2018). Perrot & Subiantoro (2018) explain that the total amount of waste generated within New Zealand has been steadily increasing over the years, and this will continue to rise in the future due to the country's economic and population growth.

The main waste management strategy of New Zealand is currently to reduce, reuse and recycle waste. Up until 2017, the nation exported 30,000 tons of plastic waste annually which has been directly impacted by China's decision to restrict imports of plastic (Perrot & Subiantoro, 2018). This ban has resulted in an increased amount of plastic waste being sent to landfill which would otherwise have been sent overseas. A significant amount of this waste is plastic packaging, with it being the biggest contributor to waste plastic (Hopewell et al., 2009).

New Zealand has a strong focus on the export of dairy products and they play an important role in the country's economy (Workman, 2020). Fonterra is the largest company in New Zealand, and contributes to approximately 30% of the world's dairy exports (Howard, 2016). However, many dairy products are packaged using plastic and a large amount of this waste ends up in landfill, negatively impacting the environment. Fonterra is aware of this issue and has recently taken action to help reduce this negative impact, for example their future posts project which upcycled Anchor milk bottles into fence posts for farms (Skerrett, 2018). They have also signed New Zealand's plastic packaging declaration, aiming to have 100% recyclable, reusable or compostable packaging by 2025 (Fonterra, 2020).

In a world-first study involving the rubbish and recycling bins of 867 households nationwide, it was found that Kiwis throw out 1.76 billion plastic containers each year. The audit found that 181 million plastic of these containers have no label stating whether or not they can be recycled (Neilson, 2020). Today there are seven types of plastic which exist in New Zealand - PET, HDPE, PVC, LDPE, PP, PS, PC and ABS, with thermoplastics such as PET, PP, and PE being the only types which can be easily recycled (Hopewell et al., 2009). Product design, collection issues, as well as individual recycling behaviour are all contributing factors to New Zealand not reaching its full potential as a clean green nation (Wasteminz, n.d.). This evidence highlights the increasing amount of plastic waste New Zealand is having to deal with as a nation, indicating an urgent requirement for more efficient waste management within the country.

2.2

WASTE MANAGEMENT

Landfill, incineration and recycling are the three main methods to treat post-consumer plastic, with recycling being the most environmentally responsible option (Webb, Arnott, Crawford & Ivanova, 2013). Globally, successful recycling systems revolve around utilising modern technology for localised convenience (Cook, 2020).

LANDFILL

Landfill is perceived to be the most convenient option for managing waste, however it creates a linear material flow, and does not allow for the re-use of any resources. (Hopewell et al., 2009). As well as this, burying plastic increases its preservation, meaning it will remain in the environment for hundreds of years (Ministry for the Environment, 2019). As of 2015, only 9% of global plastic waste had been recycled, whereas 79% had accumulated in landfills or in the environment (Geyer, Jambeck & Law, 2017).

INCINERATION

In some countries burning plastic is used as a direct replacement for burning fossil fuel such as coal, and can be sent to specially built facilities to convert plastic waste into energy (Plastics New Zealand, n.d.). Non-recycled plastic is burned with all other waste which results in emissions at a level lower than those from a coal-fired facility. John Hocevar of Greenpeace explains, “As countries like China close their doors to foreign waste and an overburdened recycling industry fails to keep up with the plastic pollution crisis, incineration will increasingly be pushed as an easy alternative” (Royte, 2019. p.1).

Large waste-to-energy facilities do generate enough electricity to supply tens of thousands of houses. However, studies have shown that recycling plastic waste saves more energy (by reducing the need to extract fossil fuel and process it into new plastic) than burning it can generate (Royte, 2019). The incineration of plastic also has a negative impact on the environment as the process produces excessive greenhouse gas emissions (Plastics New Zealand, n.d.).

RECYCLING

Plastic materials can be recycled in a variety of ways and the ease of recycling varies among polymer type, package design and product type (Hopewell et al., 2009). Hopewell et al. (2009) explain that plastic can be recycled many times whilst retaining its value and functional properties. This indicates that by increasing recycling, the production of new plastic can be reduced, and negative environmental impacts can be avoided. Bicket et al. (2014) argue that this ability to repurpose used plastic makes recycling the best established solution to treat post-consumer goods.

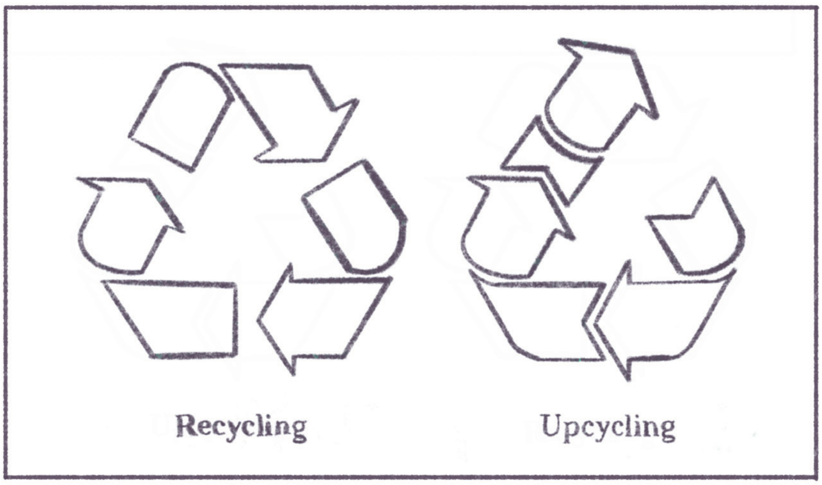


Figure 1: Recycling and upcycling

2.3

ADDITIVE MANUFACTURING

The term 'additive manufacturing' covers a broad range of production technologies that fabricate products layer-by-layer, enabling 3D objects to be produced on demand. It is inherently less wasteful than traditional subtractive methods of production, making it stand out as a production method with enormous potential for changing the distribution of manufacturing and society as a whole (Huang et al., 2013; Lipson & Wixson, 2012). Gebler, Schoot Uiterkamp & Visser (2014) argue that the adoption of additive manufacturing as a production method could lead to a future in which value chains are shorter, smaller, more localised and more collaborative.

The development and distribution of consumer 3D printers in homes and offices are blurring the lines between consumers and manufacturers (Ford & Despeisse, 2016). Anderson (2012) considers 3D printing as a "new industrial revolution" as he emphasises the potential of democratising manufacturing processes through online blueprints and localised production. Gershenfeld (2012) expands this concept, and describes 3D printing as part of a social transition which allows for the exchange of data, and contributes to a knowledge based economy.

Despite being the more efficient production method, additive manufacturing is not necessarily greener than traditional manufacturing due to the primary manufacturing material being constructed from new polymer (Ford & Despeisse, 2016). Ford & Despeisse (2016) explain that material traditionally considered as waste can be upcycled to manufacture luxury products using additive manufacturing. 'Perpetual Plastic Project' by Better Future Factory investigated these possibilities, by using plastic waste as an input for 3D printing (Better Future Factory, n.d.).

The materials tested were commonly used plastic types for everyday products such as plastic cups, bottles, caps and supermarket plastic bags. While the project found that some plastic types are recycled more successfully than others, it also demonstrated the potential of plastic recycling for tangible 3D printing applications. In addition to using recycled plastic as a filament, misprints and undesired outputs from 3D prints can be reclaimed and reused by grinding the plastic goods into granules, and then feeding these into a filament producing machine. The main issue with this approach is colour contamination and a reduction in the material properties of the polymer (Ford & Despeisse, 2016).

Worldwide initiatives and systems have been proposed to create a plastic filament made from waste. A project that explores this possibility is 'Print Your City', an ongoing research initiative by The New Raw. 'Print Your City' showcases a series of 3D-printed street furniture that is made from household plastic waste, created using robotic 3D-printing (The New Raw, 2017.). Ford & Despeisse (2016) explain that using recycled waste to produce goods that would otherwise have been made from new polymer will directly reduce oil usage and emissions of greenhouse gases generated from the production of new polymer. However, Fletcher & Mackay (1996) point out that if plastic is recycled into products that were previously made from other materials such as wood or concrete, then a reduction on polymer production will not be realised. This highlights the need for consideration into the range of products developed and produced through 3D printing. Ideally designs will be focused on the development of products which are otherwise constructed from the production of new polymers, as exemplified by projects such as the Perpetual Plastic Project.

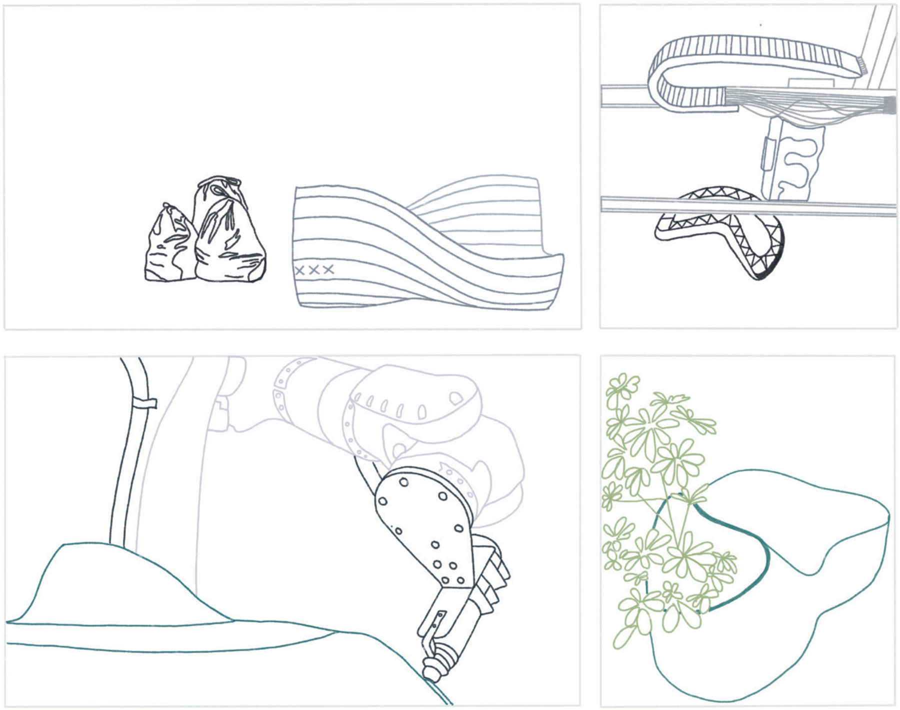


Figure 2: Benches printed from upcycled plastic.

2.4

UPCYCLING & LONGEVITY

Today, people freely replace their consumer products, with many of the replaced products ending up in the growing waste stream. Diegel, Singamneni, Reay & Withell (2010) explain that current product consumption is based upon short product life cycles, which reduces the quality of connection between the product and the user. Hopewell et al. (2009) elaborate on this within their research, finding that approximately 50% of plastics are produced for single-use applications around the world. Replacing and eventually disposing of products creates an environmental burden, as it produces waste through a linear product life cycle and uses up scarce resources needed for the production of new consumer products. Cooper (2016) suggests that a strategy towards product longevity is necessary to reduce the negative environmental effects of consumers' replacement.

The term 'upcycling' was invented by McDonough & Braungart (2002) in their book, 'Cradle to Cradle: Remaking the Way We Make Things'. The concept has attracted growing support from the general public, with circular economies being a central topic at the World Economic Forum in January 2016 (Wegener & Aakjær, 2016). It describes an approach in which waste materials are converted into something of higher quality or value in a second life (Herman et al., 2018). Conventional recycling strategies based on mechanical recycling methods or incineration are 'downcycling' approaches. These recycling methods usually lead to products with a lower material quality than the original plastic, as well as being an inefficient use of energy (Ross, 2019). Herman et al. (2018) explain that upcycling is regarded as one of the most sustainable circular solutions due to the low amount of energy required for production, as well as the reduction of the need for new products.

Upcycling allows people to engage with the making process and easily update objects or components. Bramston & Maycroft (2014) argue that upcycling is a useful tool for increasing product longevity, as the process of upcycling an object creates sentimental value for people. As well as this, the customisable qualities of upcycling means people are able to make things which may hold meaning for them such as a character from their favourite TV show.

Spinuzzi (2005) explains how methods such as participatory design can provide another strategy for increasing attachment to a product by involving consumers in the design process, co-creating their own products. Mugge, Schoormans & Schifferstein (2005) explain that when people are involved in creating their own products, they are given a personal touch and can represent an expression of the person's personality. Van Nes & Cramer (2005) argue that another value of the personalisation strategy is that people tend to become more attached to products that symbolise a personal accomplishment. Sentimental attachment is rarely found in products created outside of the user's personal experiences, emphasising the opportunity for upcycling, as well as methods such as participatory design, to increase product longevity and encourage a shift towards a more circular economy.

Recently there have been various projects which explore innovative strategies to increase product longevity through collaborating with people. In 2015, IKEA started an annual drawing competition which invites children from around the world to participate in the co-creation of a special collection of soft toys (IKEA, 2015). Children are asked to imagine and illustrate their 'dream' soft toy. Thousands of contributions are received each year, and the top designs are manufactured for sale across all IKEA stores for a limited time, with proceeds going towards a children's charity. The popularity of this project highlights the potential for the co-creation of products to increase product longevity through sentimental attachment.

In 2018, European based company ecoBirdy created a system that encourages children to recycle their old, unused plastic toys into the design and production of furniture pieces for children. As a part of this project, a school programme has been designed, along with a storybook, to introduce children to circular economies. This system has a focus on social and environmental responsibility, with the aim being to inspire children to contribute to a more sustainable future (ecoBirdy, 2018). Designs were exhibited to raise awareness during Milan Design Week 2018, garnering significant interest with 20,000 people visiting in one week (ecoBirdy, 2020). This highlights the growing awareness among society regarding sustainable issues.

Figure 3: Annual soft toy collections. Reprinted from IKEA. *Good cause campaign: Soft toys for education, 2015.* Retrieved from https://www.ikea.com/ms/en_JO/good-cause-campaign/soft-toys-for-education/kids-design-for-good-cause/index.html. Copyright (2018) by Inter IKEA Systems B.V. Reprinted with permission.

Figure 4: ecoBirdy products and school participation. Reprinted from ecoBirdy. *School programme, 2018.* Retrieved from https://www.ecobirdy.com/blogs/news/school-programme. Copyright (2020) by ecoBirdy. Reprinted with permission.

2.5

SUSTAINABILITY

Hakio & Mattelmäki (2019) explain that due to the growing awareness of our impact on the environment, many areas of design have focused on working in the fields of systemic change and transitioning towards a more sustainable society. Design for sustainability considers the environmental and social impacts of a product, service or system at the same level that economic concerns are considered (Bhamra & Lofthouse, 2007). Bhamra, Hernandez & Mawle (2013) argue that in order to design sustainably, a holistic perspective must be taken to consider all the life cycle stages of the product, from the extraction of raw materials to the potential end-of-life scenarios.

A range of issues including increasing global population, resource constraints, and social and technological innovations has created a growing consensus within the global population of the need to transition away from a linear economy, and move towards a more circular one (Charter, 2018). An example of a design project working on systematic change towards a more circular economy is ‘Precious Plastic’, founded by Dave Hakkens. ‘Precious Plastic’ provides open-source access to machines and tools that allow individual consumers to set up their own miniature recycling company, building a global community committed to targeting the issue of plastic pollution (Rhodes, 2014). It is a combination of people, machines, platforms and knowledge with the aim of creating an alternative global recycling system (Precious Plastic, n.d.). These machines are designed to process used plastic in a range of familiar manufacturing methods, allowing consumers to take the recycling process into their own hands. Since 2013, the project has undergone several different versions, iterating upon how the system can develop more holistic, circular life cycles for plastic. Development of the online platform has allowed for the global availability of a multitude of features which are beneficial to local communities such as maps, how-tos and an online marketplace (Precious Plastic, n.d.).

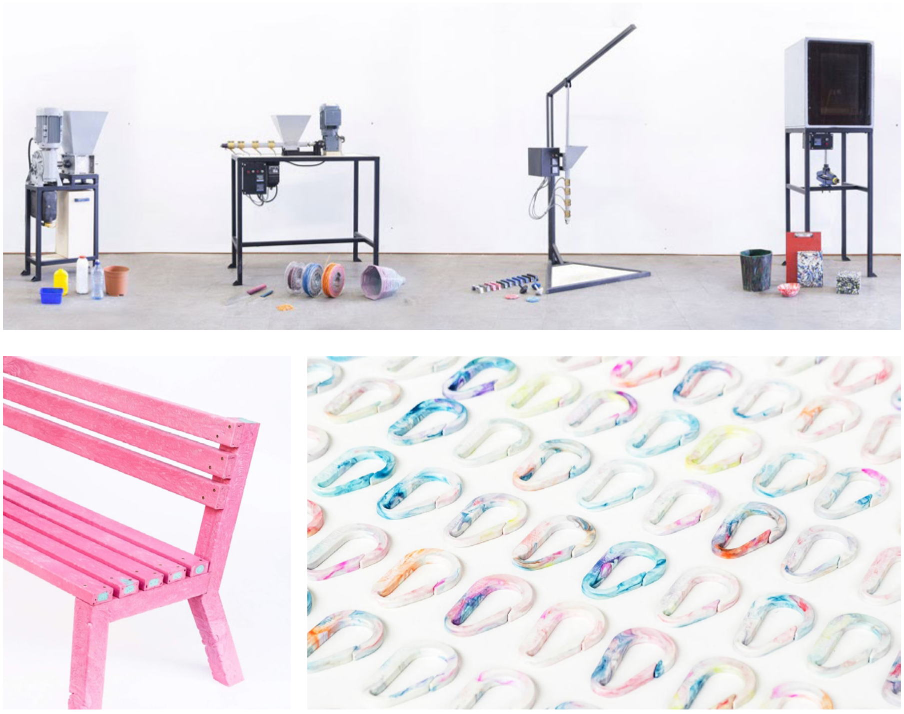


Figure 5: Precious Plastic machines and products. Reprinted from Precious Plastic. *Precious Plastic Machines, n.d.* Retrieved from https://preciousplastic.com/solutions/machines/overview.html. Licensed by Creative Commons.

Gaziulusoy & Ryan (2017) argue that transitions towards a circular economy will require significant structural changes within society, and the re-conceptualisation of new systems. Elaborating on this idea, they explain that the utilisation of creative skills in order to imagine alternative, desirable futures will be critical to the development of these systems. This reconception of the future will involve reimagining infrastructures including education (Irwin, 2015).

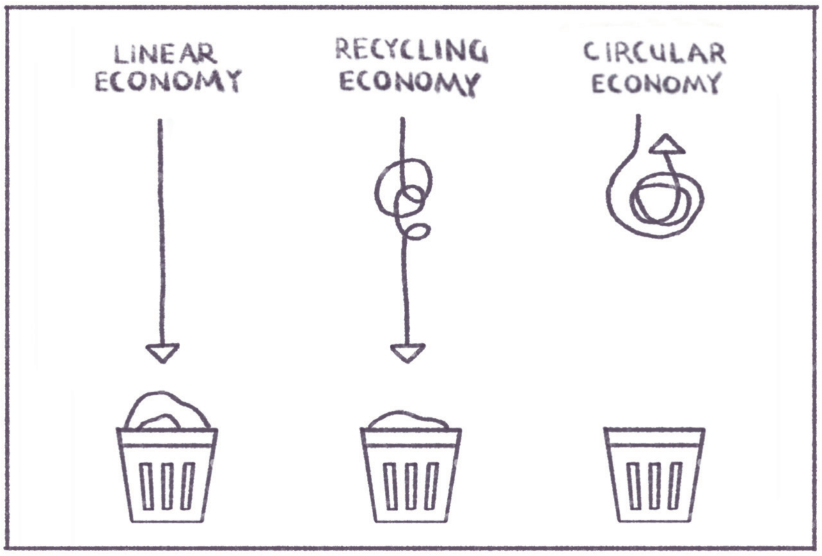


Figure 6: Linear, recycling and circular economies

2.6

EDUCATION

Taylor et al. (2015) advocate that in our current environment, education for sustainability must be a major focus. They argue that given that young children will become the next generation of adults, it is vital that they are educated about sustainability so they can be critically aware of issues such as plastic pollution, and take positive action to help preserve their future in a rapidly changing world. Previous research has also demonstrated that children's school environments are formative in establishing dispositions of environmental ethics (Chawla, 2007).

The New Zealand Curriculum encourages teachers to 'develop sustainable citizens', and have developed a focus on education for sustainability in primary schools (Taylor et al., 2015). The Ministry of Education also includes the following statement relating to education for sustainability (Ministry of Education, 2020, para 5):

> Mō tātou te Taiao ko te Atawhai
> Mō tātou te Taiao ko te Oranga
> It is for us to care for and look after the environment to ensure its wellbeing
> In doing so we ensure our own wellbeing and that of our future generations.

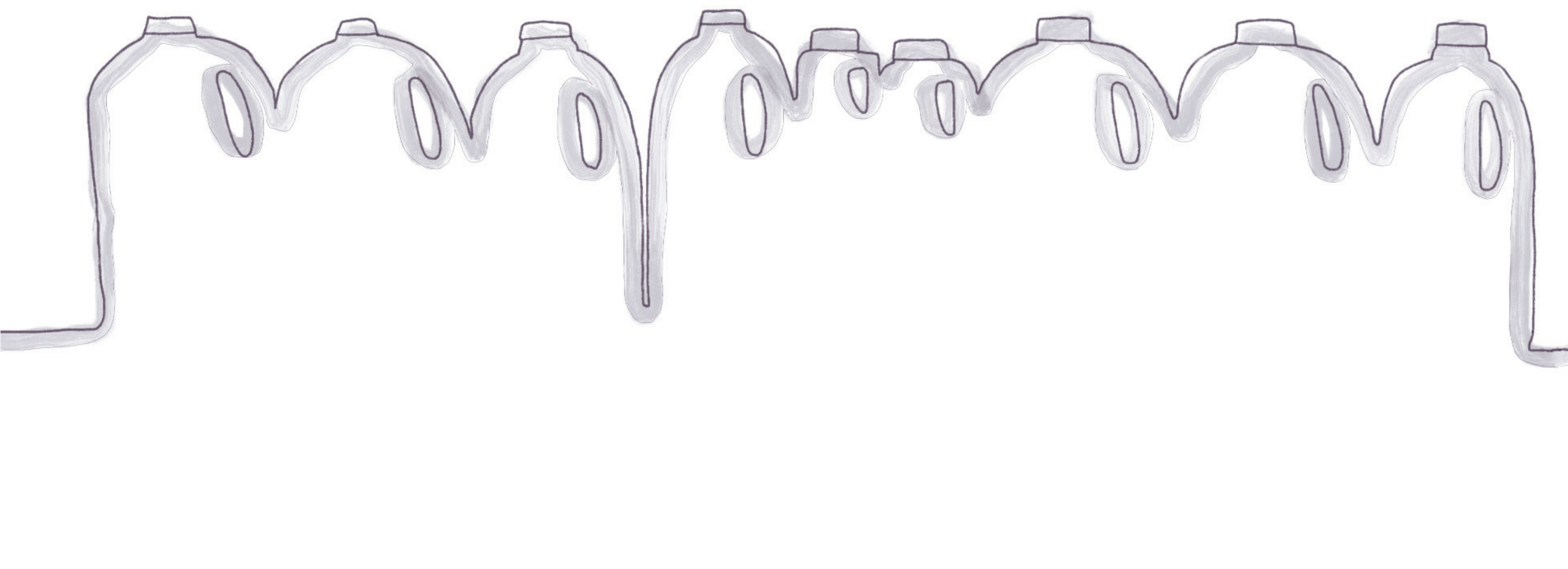
Grassroots development of education for sustainability in primary schools has been growing as greater awareness of environmental and sustainability issues becomes more prominent in society. At the beginning of 2014, over 920 schools and early childhood centres (approximately 35% of all New Zealand schools) were involved in Enviroschools, an environmental programme designed to support sustainable projects within New Zealand schools (Taylor, et al., 2015). Within the programme, individual schools choose projects to work on within the themes of 'Living Landscapes', 'Ecological Buildings', 'Healthy Water', 'Precious Energy' and 'Zero Waste' (Enviroschools, n.d.). The increasing number of schools adopting these programmes shows the growing awareness of the need for sustainability to be taught in New Zealand schools.

Engaging students with topics such as plastic upcycling from an early age may lead to them developing more sustainable habits in the future, as they will be more aware of the impacts plastic waste has on our environment (Wake & Cha, 2012). Traditionally, it was thought that simply educating children about their environment would help contribute to a sustainable future. However, studies found that in order to make an impact, education requires students to question those actions of society that lead to environmental degradation, and to engage in positive action for the environment themselves (Taylor, et al., 2015).

SUMMARY

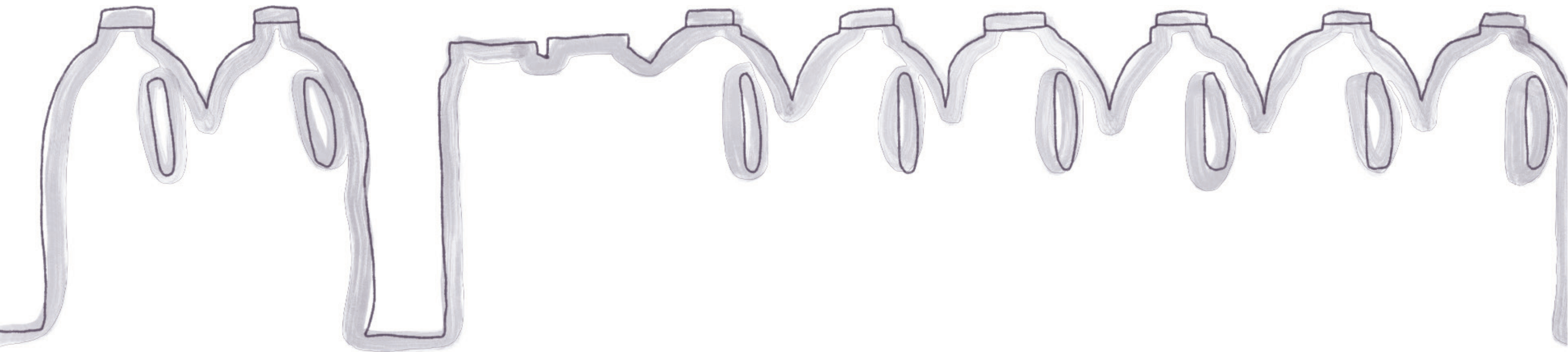
The plastic debris that pollutes our natural environment is a complex global issue that cannot be solved within the context of a single discipline (Lebreton et al., 2012). An understanding of the many factors that influence the environment, particularly the impact that humans and their behaviours have on it, is a critical step towards a more sustainable future (Ministry of Education, 2020). Education for sustainability is a way of helping individuals and societies to resolve fundamental issues relating to the current and future use of the world's resources. However, simply raising awareness of these issues is insufficient to bring about radical change. Education for sustainability must strongly promote the need for personal initiatives and social participation to build sustainable practices (Taylor et al., 2015).

Bramston & Maycroft (2014) explain that the upcycling process has the potential to engage people with more sustainable production methods such as 3D printing. Although the New Zealand National Curriculum currently teaches students about sustainability, the method of teaching remains conventional and does not explore the empirical, tactile learning opportunities that 3D printing provides. This highlights the potential for more tangible engagement within sustainability education in New Zealand, through the development of an education programme focused on 3D printed upcycling.



03

METHODOLOGY



3.1

AIMS & OBJECTIVES

Following the initial background research, this research methodology was constructed in order to explore the potential for an education programme which engages students with production methods such as upcycling and 3D printing. Research through design has been employed in order to generate practice-based research, involving developing formulas for filaments and a variety of 3D printed design outputs. In accordance with the recommendations of both Spinuzzi (2005) and Bramston & Maycroft (2014), participatory design has been incorporated as a qualitative research method in order to investigate how 3D printing and upcycling can engage students through tangible, creative learning. Prior to the research process, the following aims and objectives were identified:

AIM 01 + OBJECTIVES

Discover the potential of using 3D printing technology as a tool for the upcycling of single-use plastic waste

- Develop formulas for filaments that have the capability to be used for 3D printed applications, upcycled from a variety of single-use dairy packaging

- Investigate the potential of using upcycled filament for the 3D printing of educational tools which could be used within the context of New Zealand schools

AIM 02 + OBJECTIVES

Explore and demonstrate the potential of using 3D printed, upcycled plastic waste within the context of education

- Evaluate the potential to engage students with 3D printing technologies through the development of a proposal for a New Zealand education programme focused on 3D printed upcycling

- Apply and demonstrate 3D printed upcycling through a variety of design outputs which could be integrated into a series of project plans for the proposed education programme in New Zealand

In order to address aim 01 - *Discover the potential of using 3D printing technology as a tool for the upcycling of single-use plastic waste*, material and design experimentation was conducted to develop formulas for filament upcycled from plastic waste, and investigate the potential of using this filament for 3D printing. Research through design, involving processes such as design ideation, concept visualisation, and the development of filament suitable for 3D printing was the primary methodology for this stage of this research.

In order to address aim 02 - *Explore and demonstrate the potential of using 3D printed, upcycled plastic waste within the context of education,* qualitative data was gathered through the use of participatory design. Participatory design processes such as observations, focus groups, cultural probes and surveys were utilised in order to construct an informed understanding of the topic of upcycling and 3D printing within education, drawing upon the unique experiences of students and teachers around New Zealand. Research findings were then combined into the development of a proposal for an education programme focused on 3D printed upcycling, and a series of project plans which could be integrated into the programme.

3.2

RESEARCH METHODOLOGIES

RESEARCH THROUGH DESIGN

Research through design has been used as a distinct term within the design community for over 20 years, as a way of describing practice based inquiry that generates transferable knowledge (Durrant, Vines, Wallace & Yee, 2017). Frankel & Racine (2010) explain that in this approach, the emphasis is on the research objective of creating design knowledge, not the project solution. It generally consists of materials research, development work, and the act of recording and communicating the steps, experiments, and iterations of design (Martin & Hannington, 2012). Research through design aims to provide an explanation or theory that can be used in future projects through reflection on the design process (Frankel & Racine, 2010). Research through design was the primary methodology for the material and design experimentation. Outcomes from this stage aimed to generate design knowledge that can be used as a transferable model applicable to schools across New Zealand, considering and integrating qualitative data generated from the participatory research.

PARTICIPATORY DESIGN

Participatory design is a concept which originated in Scandinavia in the 1970's, and can be defined as a research method which "argues in favour of the possibility, the significance, and the usefulness of involving research partners in the knowledge production process" (Bergold & Thomas, 2012, p.2). Spinuzzi (2005) explains that participatory design emphasises the value of people's tacit knowledge, and integrates that knowledge into the development of new systems that empower the people it has been designed for. It is typically characterised by three phases: an initial exploration of users and their environments, discovery of users' goals, values, and desired outcomes, and prototyping of artefacts (Spinuzzi, 2005). In order to develop a framework for an education programme focusing on 3D printing and upcycling, it was important to involve both students and teachers in the research process in order to understand what would be feasible and effective. Qualitative data was gathered through the use of participatory research methods at three schools in New Zealand, which included observation, focus groups, cultural probes, and a teacher survey. These findings were used to inspire design decisions further into the research project, with a more informed understanding of what students and teachers would want and need from an education programme.

3.3

RESEARCH THROUGH DESIGN METHODS

MATERIAL EXPERIMENTATION

Using plastic waste from dairy products supplied by Fonterra, experiments involving collected plastic waste were conducted to formulate filaments suitable for 3D printing, while remaining practical for use within the context of the school environment. Materials were first sorted, granulated and processed into plastic waste filament. Test prints were conducted in order to analyse the materiality, structure and aesthetic qualities of the filament. The results of these experiments aimed to demonstrate how recycled filament could be integrated within a 3D printing education programme and communicate findings through a variety of material and design outputs.

CONCEPT DEVELOPMENT

Following the development of filaments, design concepts were generated based upon the qualitative data generated in the participatory research. Following the model for research through design, outlined by Rodriguez (2017), the criteria were established as the starting point for experimentation, which were then used for reference in the development of the final designs. Rodriguez (2017) explains that this approach is beneficial for designers in constructing explicit knowledge through the assessment of the design using clear criteria, and allows for clear communication of research findings.

3.4

PARTICIPATORY RESEARCH METHODS

OBSERVATION

To attain a sufficiently cognisant understanding of the physical and social dynamics within the typical classroom environment, especially as they relate to 3D printing, observations were conducted as the first stage of the research. These were carried out over a two-day period at School 01 in Auckland, where time was spent with students and teachers to learn more about their everyday environment. This provided initial insight into contextual environments and learning relating to plastic waste, upcycling and 3D printing.

FOCUS GROUP

McElroy (1997) explains that the main aim of a focus group is to generate qualitative data which provides insight into the attitudes, perceptions and opinions of research participants. Two classes from School 02 in Wellington were invited to participate in a focus group which involved a presentation and various activities. The presentation followed a structure of three themes: plastic waste, upcycling and 3D printing. A predetermined structure which also allows for flexibility and discussion is preferable for participants, particularly young people (Gibson, 2007). Accordingly, at the conclusion of each theme a brief activity was introduced encouraging students to share thoughts and ideas in a creative way.

CULTURAL PROBES

A range of cultural probes were also used to gather qualitative data from students to discover their thoughts, experiences and ideas on plastic waste, upcycling and 3D printing. Cultural probes are an exploratory research method, and aim to identify key patterns and themes that may emerge from participants through imaginative activities. Martin and Hannington (2012) suggest that the materials created for probe kits should be varied and imaginative in order to elicit relevant responses to the design enquiry. This advice was considered in the development of a variety of lessons and activities, released on Google Classroom for students to access and complete as homework over a two week period. Students at School 03 in Wellington were introduced to this research in class through their teacher, which was advised by the school as the best approach. A total of three lessons were presented to students along with a corresponding activity to each, these were about plastic waste, upcycling and 3D printing.

QUESTIONNAIRE

Initially a short questionnaire containing 8 questions for students was used to gain insight into students' thoughts and experiences regarding 3D printing. Questions mainly regarded whether students had any experience with 3D printing technology, and what their opinions were about it.

DAIRY DIARY

Along with the lesson about plastic waste which informed students on how to identify plastic types, participants were asked to keep a record of any single-use dairy plastic packaging they were throwing away at home. Participants were also asked to note down and tally the product, size/volume, colour and the plastic type that was being thrown away. The purpose of the 'Dairy Diary' was to investigate how receptive students would be to the idea of recycling as a school group activity.

It was also a way to find out how much plastic waste could potentially be collected by students.

COLLECT

Activity 3 consisted of a 'Collect' activity, where students were asked to collect plastic bottle caps from a variety of dairy products. They were also asked to clean the bottle caps, which referred to information included within the plastic waste lesson about the importance of cleaning waste. This was to give insight into the motivation and ability of students to collect and properly clean plastic waste for the development of upcycled filament.

DRAW

Finally, the 'Draw' activity asked students to think of something they would like to 3D print and create a simple drawing of their idea. Fargas-Malet, McSherry, Larkin, & Robinson (2010) explain that drawing is a particularly fun and engaging way for children to express their ideas and experiences, particularly if they are less inclined to contribute to conversation. The results from this activity were used to help discover what it is students themselves are wanting to 3D print. The ideas were then integrated into the design of 3D models to assist and inspire the development of 3D printing programme scenarios.

TEACHER PARTICIPATION

As well as conducting research which aims to consider and integrate the thoughts and experience of students, teachers in the Wellington region were also approached to participate in the research through a voluntary, anonymous survey. Teachers were identified as a valuable source of knowledge in helping to form a more holistic understanding of the potential for a plastic waste upcycling and 3D printing programme within New Zealand schools.

SURVEY

A voluntary, anonymous online survey was provided for teaching staff in various schools in the Wellington region. As explained by Walonick (1993), surveys present a discreet, non-obligatory way for interested teachers to participate in a meaningful way in their own time, at their own discretion. The surveys contained open-ended questions about: school waste management, practices and policy, sustainability and waste management within the curriculum, and 3D printing within the curriculum. Using a straightforward and time-effective method was particularly important with teachers being the participants, as they are often very busy and thus less likely to have time to contribute towards external research. The combination of both written-answer and scale graph questions resulted in both quantifiable data and qualitative reflections for further analysis.

3.5

ETHICS

ETHICS APPLICATION

This research is categorised as high-risk because participants, being aged under 16, are considered vulnerable. As such, an ethics application #0000027808 was submitted and subsequently granted by Victoria University of Wellington's Human Ethics Committee on the 15th of November 2019.

RECRUITMENT PROCESS

This research sought to develop an understanding of the thoughts and experiences of students in relation to plastic waste, upcycling and 3D printing. As such, three schools were recruited for the observation, focus group and cultural probe activities. The participants involved in this study were recruited through the Wellington Faculty of Science's existing outreach networks and partner schools. The author had repeated contact with teachers from the schools throughout the research process, to establish rapport and a credible basis for qualitative research. Each of the schools had previously participated in 3D printing programmes, and had expressed an interest in further developing upcycled 3D printing education within their school. Participants from the schools were aged between 10 and 15 years old. The only exclusion criterion was if students themselves or their parents did not want to participate in this research. All ethics documentation can be found in Appendix B.

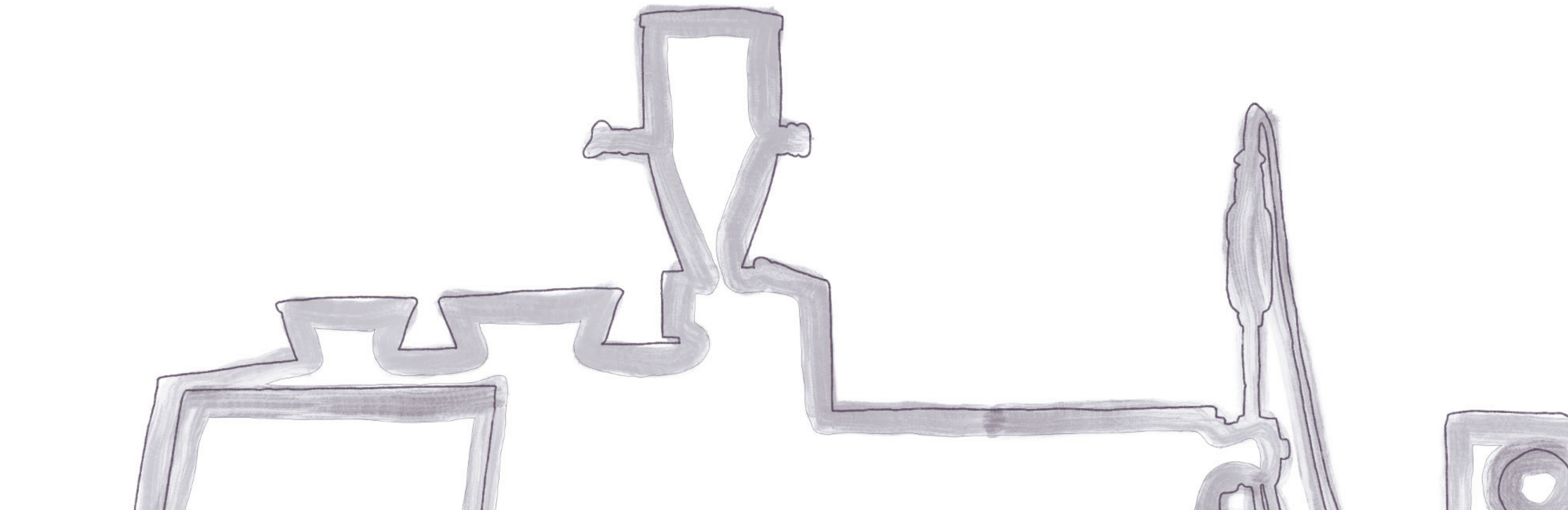
Before initiating data collection, the author met online through Zoom with each participating school. This allowed the author to ask more fundamental questions about their previous experience teaching 3D printing to their students and how the research could align with their in-class learning. This was also an opportunity for the teachers to ask the author any questions or bring up any concerns they had about the research.

As each of the schools involved had used 3D printing within their learning previously, they had pre-existing ideas and expectations about the potential for 3D printing technologies. Although schools had previously been involved with 3D printing, not all students participating in this research had 3D printed an object. This established a sound basis for a range of opinions and experiences relating to 3D printing. One of the schools had already integrated 3D printing into their technology curriculum, and had completed a number of projects in this area. For two consecutive years, the students had used Autodesk's TinkerCAD to model a buzzy bee. The best buzzy bees had then been 3D printed using the school's 3D printers. The remaining schools did not have 3D printing integrated within their curriculum, but had experience with 3D printing programmes in the past and had access to at least one 3D printer at the school.

Participants who took part in the research are listed in Table 1. In each of the chapters following it will be stated which participants' involvement is reported on.

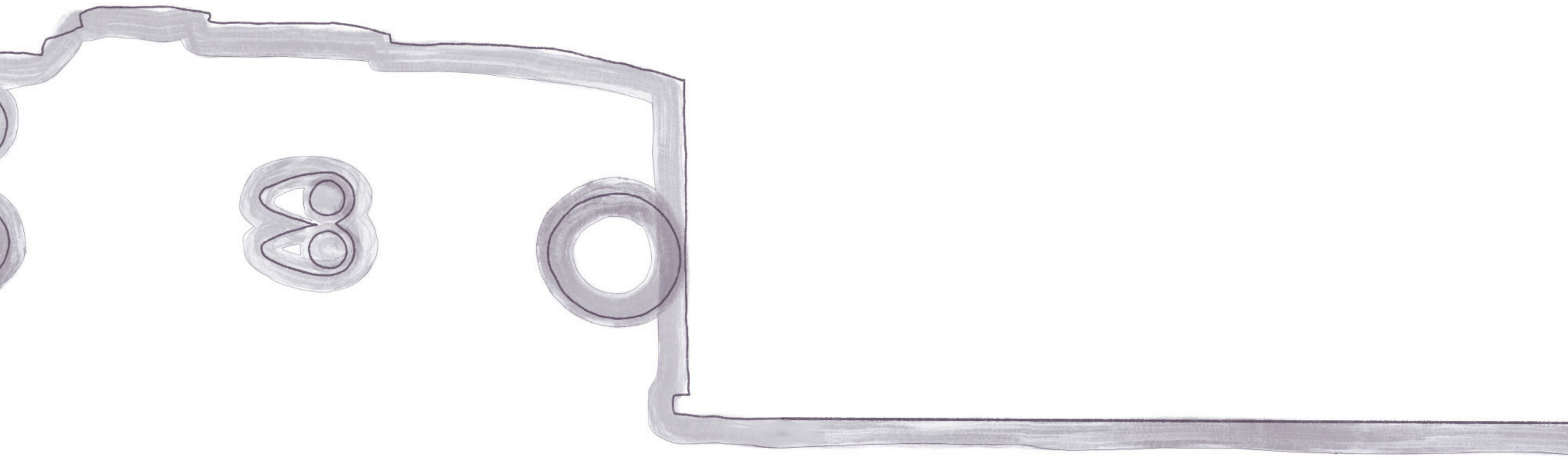
School	Age	Participants	Activity	Session
School 01	Years 7 - 10	-	Observation	Group
School 02	Year 9	27	List Sensory Draw	Group Individual
School 03	Year 8	73	Questionnaire Dairy Diary Draw Collect	Individual
Teachers	-	-	Survey	Individual

Table 1: Research participants



04

MATERIAL EXPERIMENTATION



4.1

PROCESS & TECHNOLOGIES

Material research was carried out using the equipment in Victoria University's recycling laboratory. This stage of the research aimed to develop formulas for filaments upcycled from single-use plastic waste, as well as investigate the potential of using upcycled filament for 3D printing within New Zealand schools. Initial tests and experiments were conducted to understand the filament making process further and establish a refined method of producing 3D filament.

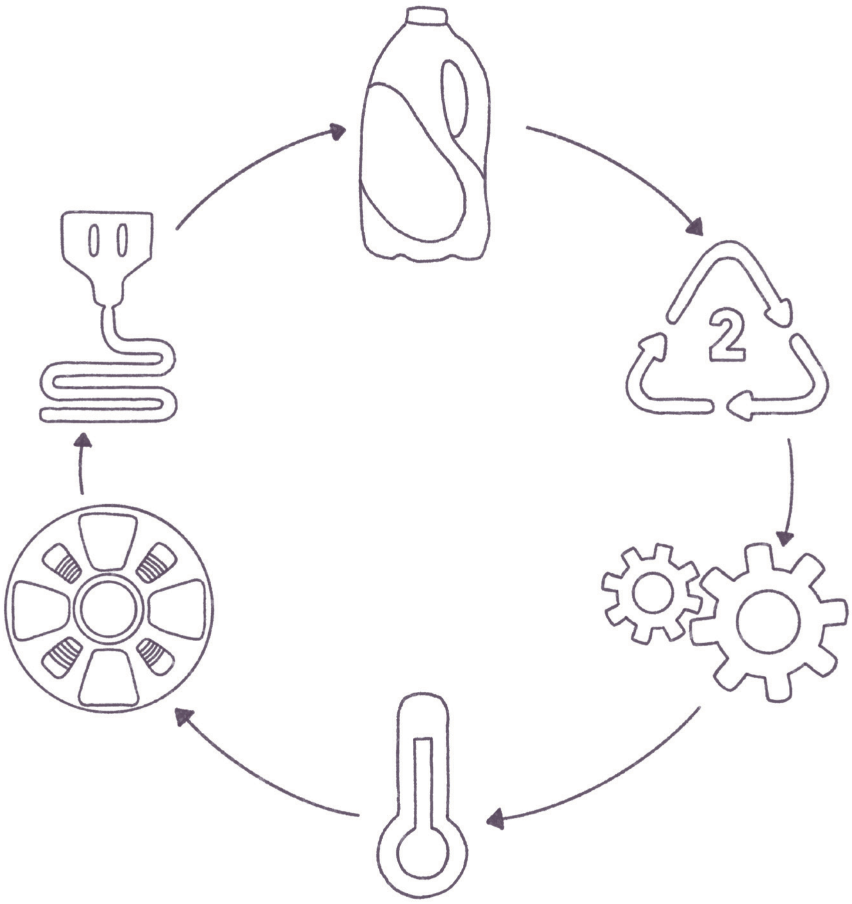


Figure 7: Graphic representation of the upcycling process

FILAMENT PROCESSING EQUIPMENT

The process of making upcycled filament first involves the collection and cleaning of plastic. The plastic is then processed using a granulator, with sorted plastic material being placed into the top chute to be processed and ground by metal blades. It is then passed through a mesh, sorting smaller particles suitable for the extrusion process. Once the plastic has been granulated, it must be dried using a drying oven. The oven is used to extract moisture from the material in order to form filaments in a more reliable and consistent manner. If this process is missed, it can result in material that will likely become brittle and extrude, spool or 3D print inefficiently. The oven's temperature can be adjusted to not only dry plastic, but also melt it into slabs. Dried plastic granules can then be processed into filament using an extruder, which melts and extrudes the plastic. Once melted, plastic is loaded onto a spooler which cools and forms the extruded plastic into filament. Filaments that have extruded inconsistently can be fed through an additional granulator which cuts the extruded plastic into small pellets to be reused. This prevents materials being wasted during the experimenting stage, as well as being a necessary requirement to decrease the size of foil particles in the PE plastic, discussed later.

The following equipment (Figure 8) in was used to process the plastic into upcycled filament:

- **Conair 8 series granulator**
- **Contherm thermotec 2000 oven**
- **Thermo Scientific Process 11 twin-screw extruder, spooler and granulator**

Figure 8: Granulator, oven, extruder, spooler and pelletiser

COLLECTING & SORTING

A range of different plastic types was supplied by Fonterra and collected locally to begin experimentation with, these materials included:

- **HDPE** (high-density polyethylene), granulated Anchor milk bottles
- **HDPE,** various coloured bottle caps
- **PE** (polyethylene), yoghurt foil pouches with a plastic spout attached
- **HIPS** (high impact polystyrene), unformed sheets for yoghurt containers
- **HIPS,** formed yoghurt containers with glued paper labels

To prepare the materials for granulating it was essential to ensure all plastic had been thoroughly cleaned, as it is easier to clean in its full form, rather than once it is granulated. Plastic supplied from Fonterra did not need cleaning as it had not yet been used to supply food products. The bottle caps had been collected from various places and needed to be thoroughly washed in hot soapy water and dried completely. They were washed by hand and dried using the drying oven at a low temperature of about 80 degrees for a few hours until dry. The yoghurt foil pouches, consisting of multiple layers of laminated materials including aluminum, needed to be separated from the plastic spout using a utility knife as the foil is highly static and would not process efficiently in the granulator. It was not possible to completely remove the foil from the spout as they were heat sealed together. This resulted in a small amount of foil still attached to the plastic part. Several attempts were made to remove the glued paper labels from the yoghurt containers, including a hot wash, alcohol solutions and oil solutions. These methods proved inefficient and did not work completely to remove the glue and paper. It was decided not to use this particular HIPS material to avoid processing a glue substance in the granulator.

Figure 9: Supplied and collected plastic

This stage demonstrated issues which occur within the upcycling process, resulting from the way plastic packaging is made. When plastic packaging combines different materials that are difficult or impossible to separate, it creates complications in the granulation and filament processing stages. This highlights the need to consider the construction of plastic packaging holistically, with a focus on it's disposal and end-of-life.

GRANULATING

Plastic materials that were collected, cleaned and sorted by type were then processed using the granulator. This process results in small plastic granules (Figure 11) that can then be extruded into filament for 3D printing. In order to avoid inconsistency within the filament, it was ensured that granules were no larger than a couple of millimetres in size.

Although the HDPE was already granulated by Fonterra, these granules needed to be reprocessed and made finer to make them suitable for the extruder. Plastic types were sorted by colour to make specific coloured filaments. The collected HDPE bottle caps were predominantly blue, with the rest being green, red and other colours. All bottle caps were combined and granulated together as there was not enough of each colour to process them separately.

Processing the PE yoghurt spouts into granules required several stages of granulation as shown in Figure 12. As the spouts were originally quite small there was not a sufficient amount of material being pulled through the blades to cut the plastic into fine pieces. Larger chunks of the plastic and foil were falling through the blades which resulted in an inconsistent grind, with granules too large to process into filament. The granules needed to be a finer consistency, however, it was difficult to reprocess granules as they were too small for the granulator to process. Therefore, to prevent wasted material the larger granules were melted into slabs. Using the drying oven at a temperature of 180 degrees and gradually increasing to 200 degrees, the plastic slabs were melted within an hour. The foil parts did not melt, however, reprocessing the slabs through the granulator made the resulting granules much finer. These resulting granules were then processed into filament and pelletised into an even finer material using the pelletiser. This final step was necessary to make the foil pieces even smaller so that they can be processed into filament more easily.

It was found that along with the finer granules which had successfully moved through all components of the granulator, there was often a slightly denser mix of granules trapped in the mesh sieve. As these granules were too large to process into filament, to prevent larger plastic pieces being left behind it was discovered that the granulator can be left running for an additional few minutes. This allows these remnants to be shredded further so they are small enough to pass through the mesh sieve. Leaving the machine on for this additional time gave a bigger yield of shredded plastic and resulted in less unusable material. If this stage was left out, a significant amount of plastic was left insufficiently granulated.

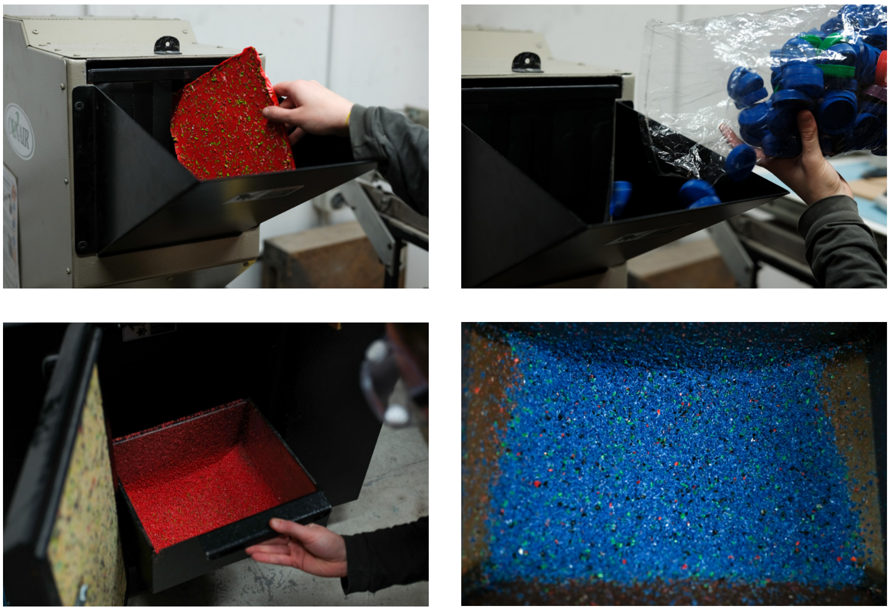


Figure 10: Granulating melted PE slabs and HDPE bottle caps

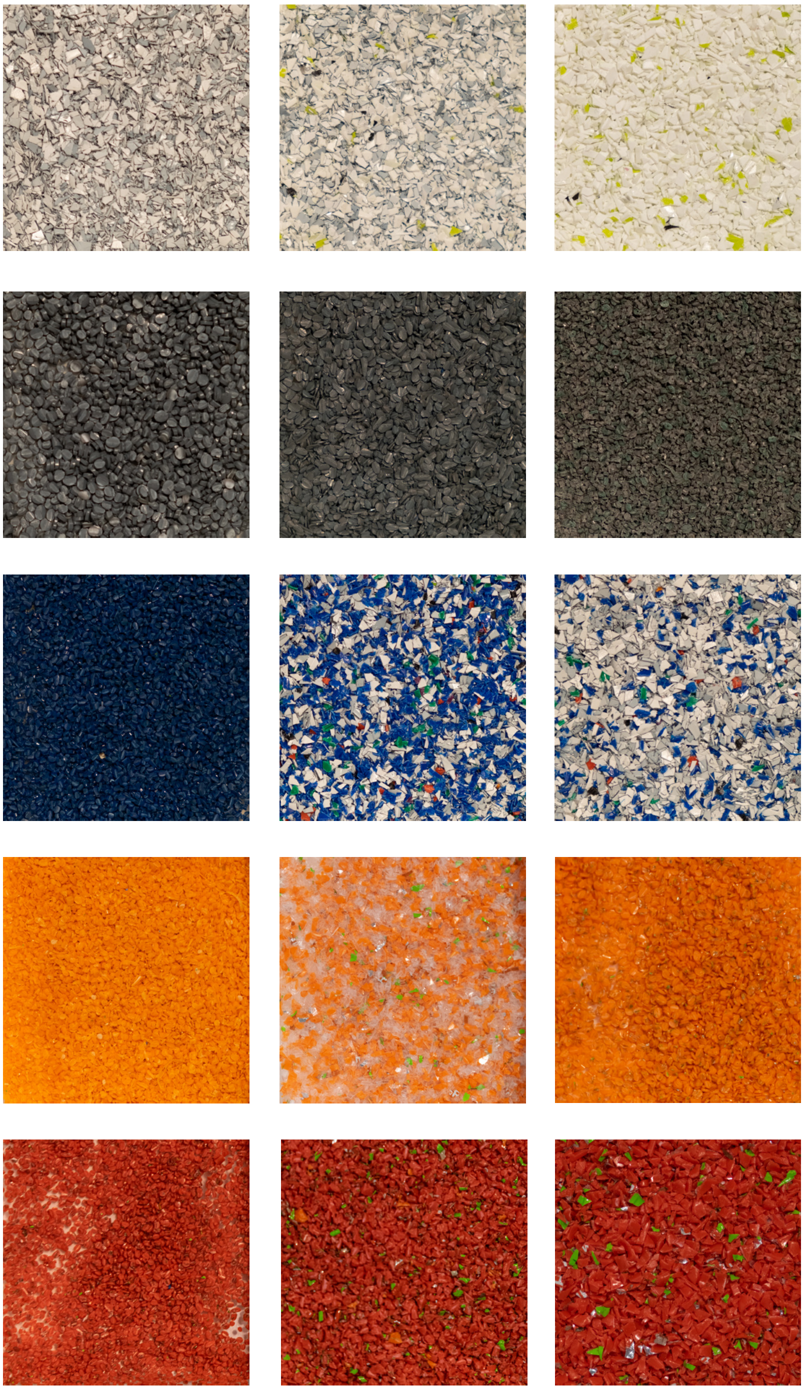


Figure 11: Various plastic granules

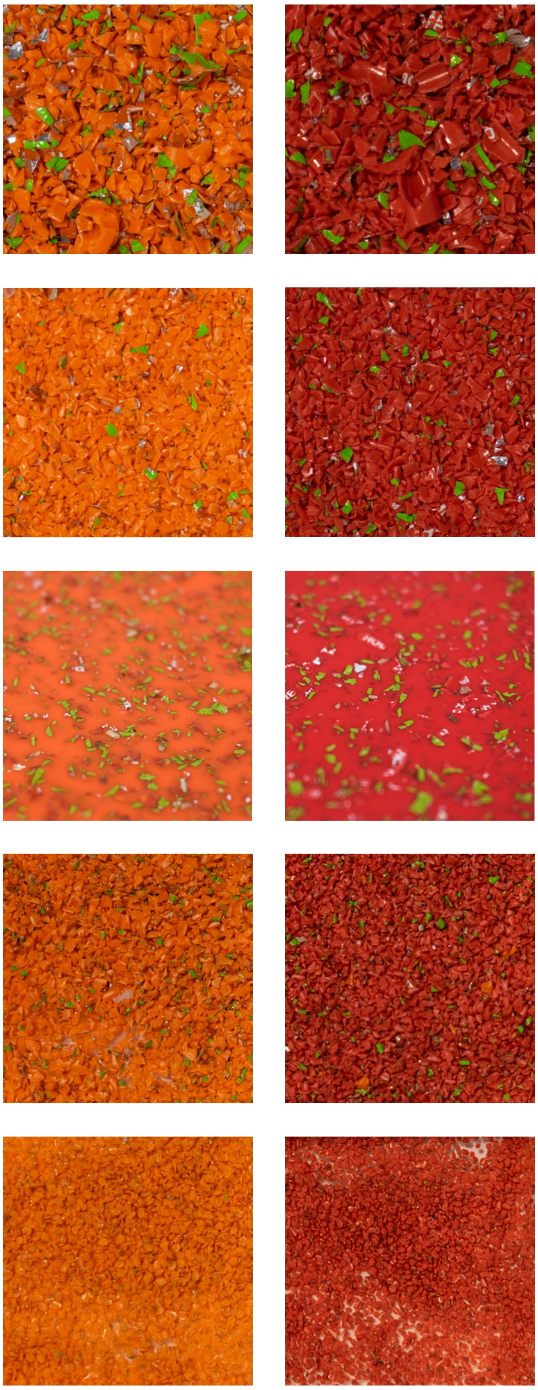


Figure 12: PE yoghurt spouts granulation process

EXTRUDING & SPOOLING

The extrusion process involves placing granulated materials into a feeder which filters the granules onto heated twin screws. Extrusion settings can be adjusted by controlling the speed at which material is passed through the machine. Temperature settings can also be controlled through several different zones, which the plastic granules pass through gradually. The temperature is initially set to low, with it gradually increasing along each zone. The final temperature will ideally be set to the desired processing point of the plastic being extruded.

During this stage, the importance of both the granules size and the requirement to dry certain plastic materials became apparent. Processing plastic with large, less refined granules resulted in inconsistent filament. This was due to the larger pieces requiring more time to melt, causing blockages within the extruder. As well as this, when plastic had not been thoroughly dried it resulted in a brittle filament that could not be spooled due to constantly snapping.

Various combinations of plastic types were trialed in order to determine whether combining polymers would result in a more resilient filament. HIPS was mixed with a small amount of HDPE in the extruding process, as the HIPS appeared to be quite brittle after being extruded into filament. This did somewhat address the issue, but the process was extremely time consuming and did not justify the small improvement in the filament. Ensuring the HIPS was thoroughly dried before extruding was found to improve the overall quality and brittleness of the filament enough so that the mixing of plastic types was not required. As well as this, further combinations of plastic types were explored such as a combination of HDPE, HIPS, and PE. However, this process was again inefficient. Once the plastics had been combined, they no longer had identifiable properties due to not being a recognisable plastic type. This meant that these mixed filaments were a lot harder to reuse, and a lot more likely to go to waste. It was decided that the use of filaments consisting of a single plastic type was the most efficient and sustainable method of processing plastic waste.

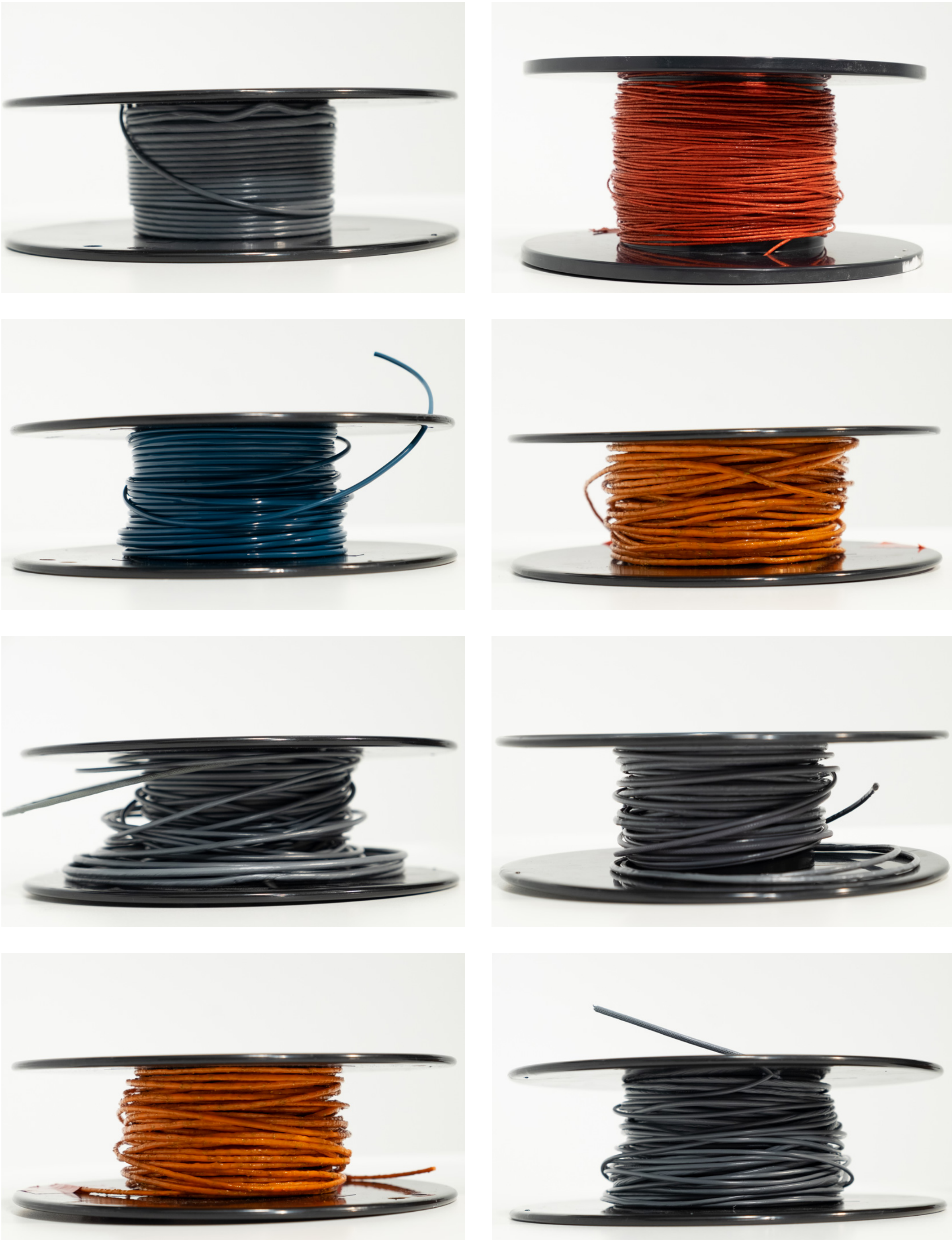


Figure 13: Upcycled filaments

Most plastic materials were able to be extruded and loaded straight to the spooler to get cooled and rolled onto a spool. However, working with the HDPE took more experimentation due to the extruded plastic twisting and creating a seam throughout the entire filament roll. This was because of the material cooling too slowly and remaining malleable during the spooling. It was found that the use of a water bath (Figure 14) before spooling HDPE significantly reduces twisting of the filament. The water bath helps to cool the HDPE, setting the plastic and resulting in a smooth filament that does not twist or form a seam.

The majority of plastic materials that were extruded and spooled had a grainy texture. This was due to either the type of plastic, or secondary materials such as foil remaining in the granules. The grey HDPE, as well as the blue HDPE bottle caps, were the only materials that produced a smooth filament. However, the most important aspect of the extruding process is that filament remains as consistent in diameter as possible. Inconsistent filament causes clogging, as well as other difficulties with extrusion when 3D printing. To address this issue, it was ensured that the filament diameter remained within a range of 2 millimetres to 3 millimetres.

Figure 14: HDPE filament extrusion and spooling process

4 . 2

MATERIAL TESTING

3D PRINTING

The final stage of material experimentation involved evaluating the ideal 3D print settings for each of the filaments. As each of the plastic filaments had unique properties, they also needed different settings for efficient 3D printing. The Ultimaker 3 was used to print the models, a 3D printer that allows for the fine tuning of a number of settings such as speed, flow rate and temperature.

3D models needed to be imported into a slicer software which is used to adjust print settings and convert the model into layers suitable for 3D printing. The file can then be exported using a file format called g-code, which is then able to be loaded and printed using the 3D printer. This step also allows for the preview of the 3D printed model, which can help to detect and avoid any potential printing errors before they occur.

Figure 15: 3D printing layer by layer

A range of test prints were conducted in order to analyse the materiality, structure and aesthetic qualities of the filament. Several elements were focused on to determine the ideal settings for the 3D printing of each of the individual filaments. These settings included:

BUILD PLATE ADHESION

The first step to producing a successful 3D print overall is ensuring the 3D print is well adhered to the build plate, which is important to prevent the print shifting. The print bed can be heated, however, this function is only suitable for certain filaments as it causes warping in others. Each of the materials had unique requirements to ensure adhesion to the print bed. A range of tapes including PE and PP tape were used to assist in the build plate adhesion. It was discovered that using tape which has the same polymer or material qualities of the plastic being printed had the most successful results. As well as this, it was found that the use of a brim (an outline of the shape which is first printed to lay a foundation) supported adhesion by creating a larger surface area for the print to adhere on. This reduced shrinkage and warping within most of the prints, and was easy to remove after printing, which would make it simple enough for students to use a technique to improve the quality of their 3D prints (Figure 16).

TEMPERATURE

Various temperatures were experimented with to determine the best material flow rate of the upcycled filaments when 3D printing. The initial testing temperatures were determined by the temperature used melting the plastic during the extrusion process. After adjusting in increments of 10 degrees, it was discovered that each of the filaments is successfully extruded at 240 degrees.

LAYER SETTINGS

Different layer height and width settings were adjusted and compared to determine the ideal combination. Smaller layers result in more defined, detailed prints whereas thicker layers result in more obviously 3D printed models with the layers being more visible. The benefit of increasing the layer height is that it reduces print time, making for quick efficient prints when the overall quality and detail of the print is not critical. Thicker layer heights worked particularly well for each of the filaments, with smaller layers having a higher chance of splitting in between layers.

INFILL

The use of infill is to help the overall strength and structure of a 3D printed object. A higher percentage of infill is necessary for more complex models in order to support each of the different layers as the model is printed. Increased infill will add only a small amount of time to the overall print. Infill was found to be useful as a structural base for models, as without it the layers would have no foundational adhesion.

Figure 16: Easy to remove brim used to support adhesion

Figure 17: 3D printing set-up and 3D print collection

THE FORMS

To determine the quality of the upcycled filaments, a series of forms were designed to test different aspects of the printability. The forms were designed to include a variety of shapes and angles to analyse the quality of the filaments over a range of 3D outputs. The following features were evaluated in a series of test prints:

- **Symmetry -** To detect any warping caused by the filaments.
- **Bridging and overhang -** To test the capability of printing across spaces and top layers.
- **Variety of planar and rounded faces -** To look for any visible surface deviations.

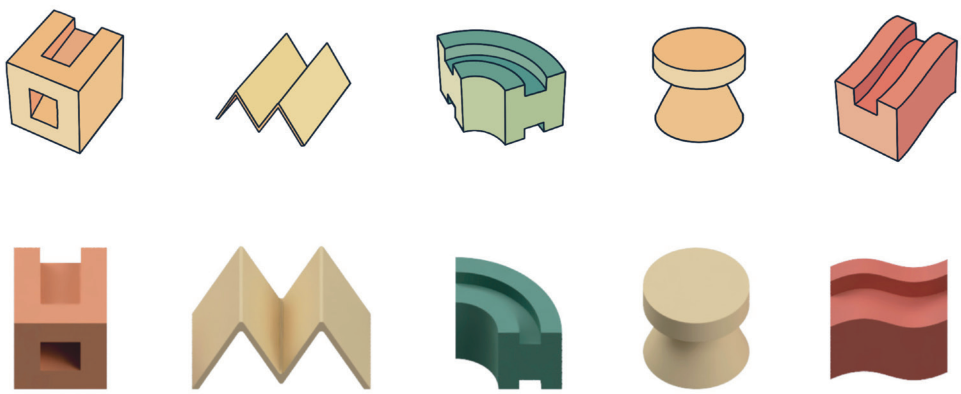


Figure 18: Testing forms

Figure 19: Failed 3D prints

4.2 MATERIAL SETTINGS

The final filaments were made using a single plastic type, after it was discovered that this was the most efficient and resilient method for making filament. This allowed the properties of the plastic to remain identifiable, and allowed for it to be reprocessed if required. There were five final filaments in total with there being two colours of HDPE, a single colour of HIPS, and two colours of PE.

PE

The PE plastic from the yoghurt spouts was made into two coloured filaments, red and orange. These filaments both had a grainy texture, with green speckles from the remnants of foil remaining in the filaments. These speckles are the result of foil which is combined with the plastic within the packaging, which makes this material non-recyclable in New Zealand. This plastic printed fairly successfully, with a lot less warping and shrinkage than the HDPE. However, there were again issues with adhesion with the filament only adhering to PE tape which would fuse with the filament. This filament produced sturdier 3D models than the other plastic types as the plastic had a higher density. Despite this filament having a grainy texture which could have potentially blocked the printing nozzle, it was still able to extrude efficiently and reliably without any issues. This packaging is not currently recyclable in New Zealand due to it being a mixture of material. Therefore, fixing the adhesion issues through further refinement would be beneficial to waste management within the country as it could then be easily upcycled through 3D printing.

HDPE

Both a blue and a grey coloured roll of filament were made from the HDPE milk bottles and caps. These filaments were the smoothest of the five, due to this plastic type having no secondary materials present such as foil or paper. Although these filaments were relatively consistent in diameter and appeared smooth, they encountered issues with warping and shrinkage when being used for 3D printing. They also struggled to adhere to the print bed, often lifting off in the early stages of printing. It was found that PE tape created the best adhesion to the bed, however, this was unable to be removed from the final print as the plastics completely fuse together. This filament did produce smooth layers which showed the potential of this plastic for 3D printing, but the adhesion problems limited its capability significantly.

HIPS

The HIPS was made from yoghurt containers, which meant that the filament was a white colour. With this being a good neutral base, this filament was coloured using plastic colour pellets consisting of various colours which created a colourful gradient throughout the filament. This filament printed very successfully, with strong reliable adhesion to the print bed with the addition of heat and glue. This filament also had a small amount of paper within it from the yoghurt labels. This was initially concerning but was found to create no problems with the printing process, instead resulting in the filament having an interesting aesthetic quality with speckles throughout the layers. The HIPS maintained a slightly brittle quality, meaning that it was more delicate than other filaments. Overall, this was the most reliable filament and produced the most accurate prints with few adhesion problems. HIPS cannot currently be recycled in New Zealand, this means that its potential to be used as a material for 3D printing outputs could reduce the amount of plastic waste being sent to landfill within the country.

HDPE - BLUE

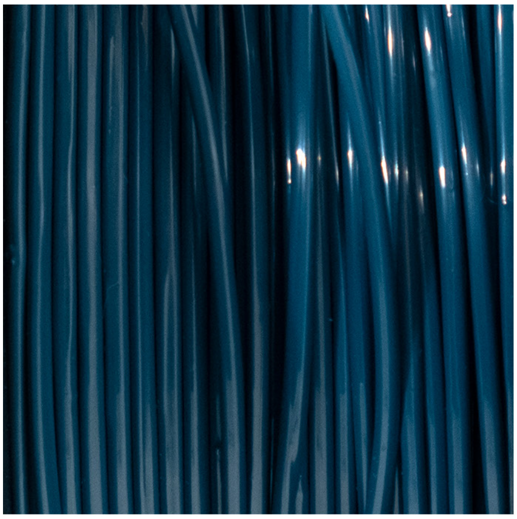
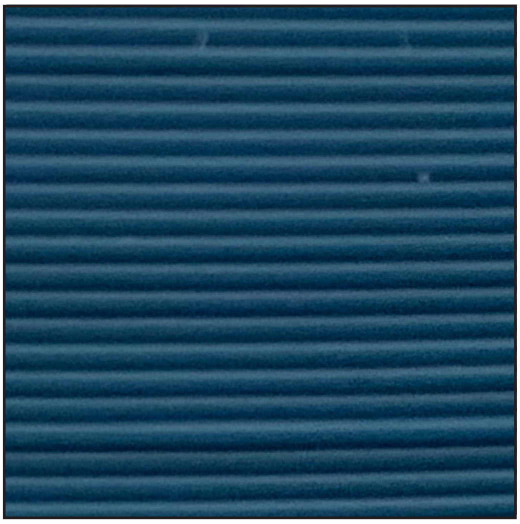



Figure 20: Blue HDPE filament and 3D print close up

Granulation	Drying temperature & time [°C/hours]	Extruder temperature [die, °C]	Extruder speed [RPM]	Filament Diameter [mm]	Quality
1	Not required	180	20	2.00 - 2.75	Smooth

Bed Adhesion [°C]	Nozzle temperature [°C]	Layer Height/ Width [mm]	3D Printing Flow Rate [%]	Print speed [mm/s]	Quality
0 + PE tape	220	0.8/1.2	110	20	Good, minor warping

Table 2: Ideal filament and 3D print settings for blue HDPE

HDPE - GREY

Figure 21: Grey HDPE filament and 3D print close up

Granulation	Drying temperature & time [°C/hours]	Extruder temperature [die, °C]	Extruder speed [RPM]	Filament Diameter [mm]	Quality
2	Not required	225	30	1.50 - 2.80	Smooth

Bed Adhesion [°C]	Nozzle temperature [°C]	Layer Height/ Width [mm]	3D Printing Flow Rate [%]	Print speed [mm/s]	Quality
0 + PE tape	220	0.8/1.2	110	20	Good, minor warping

Table 3: Ideal filament and 3D print settings for grey HDPE

PE - RED

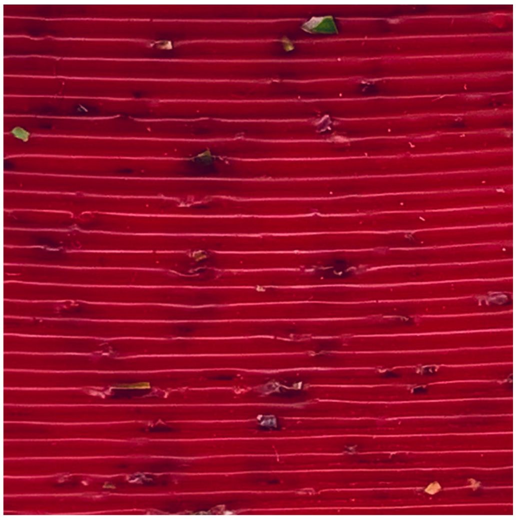



Figure 22: Red PE filament and 3D print close up

Granulation	Drying temperature & time [°C/hours]	Extruder temperature [die, °C]	Extruder speed [RPM]	Filament Diameter [mm]	Quality
4	Not required	160	25	1.92 - 2.70	Grainy

Bed Adhesion [°C]	Nozzle temperature [°C]	Layer Height/ Width [mm]	3D Printing Flow Rate [%]	Print speed [mm/s]	Quality
0 + PE tape	240	0.6/1.2	100	25	Good, minor warping

Table 4: Ideal filament and 3D print settings for red PE

PE - ORANGE

Figure 23: Orange PE filament and 3D print close up

Granulation	Drying temperature & time [°C/hours]	Extruder temperature [die, °C]	Extruder speed [RPM]	Filament Diameter [mm]	Quality
4	Not required	160	20	2.20 - 2.80	Grainy

Bed Adhesion [°C]	Nozzle temperature [°C]	Layer Height/ Width [mm]	3D Printing Flow Rate [%]	Print speed [mm/s]	Quality
0 + PE tape	240	0.6/1.2	100	25	Good, minor warping

Table 5: Ideal filament and 3D print settings for orange PE

HIPS - COLOURED

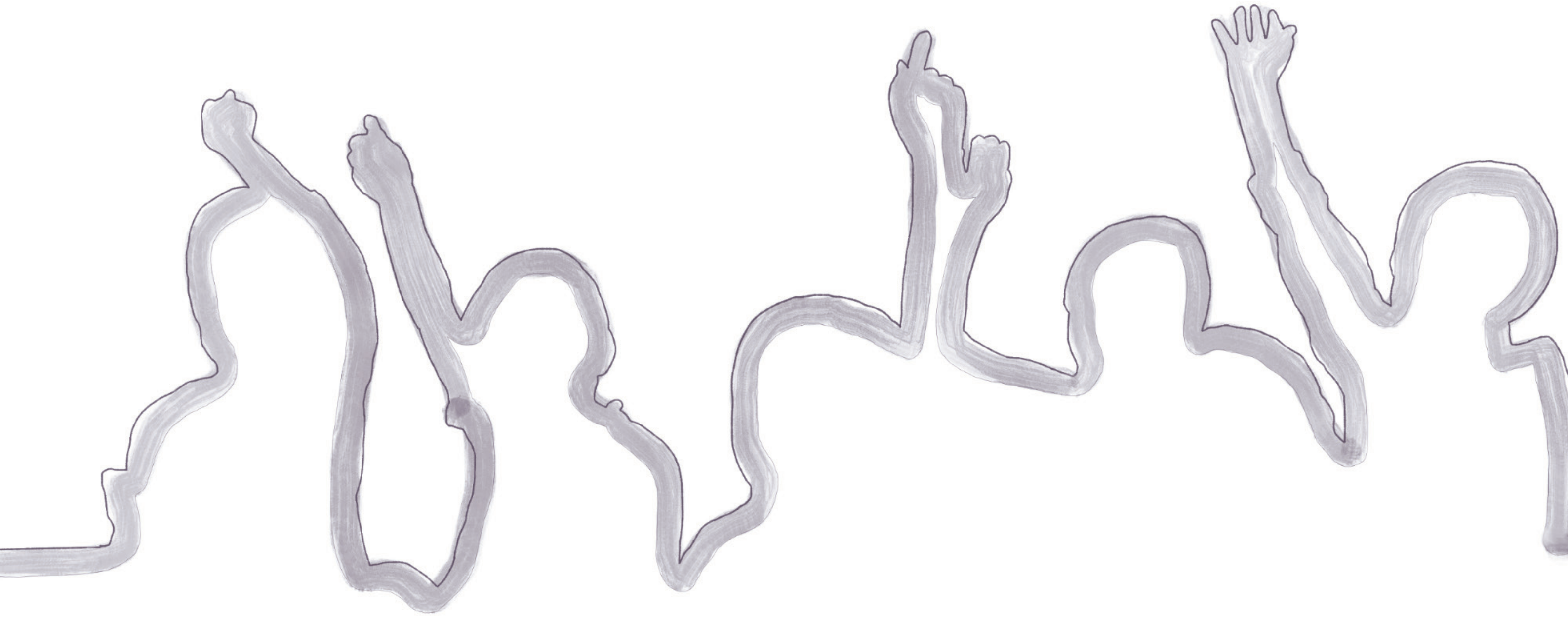
Figure 18: HIPS filament and 3D print close up

Granulation	Drying temperature & time [°C/hours]	Extruder temperature [die, °C]	Extruder speed [RPM]	Filament Diameter [mm]	Quality
2	70/6	240	46	1.88 - 2.60	Grainy

Bed Adhesion [°C]	Nozzle temperature [°C]	Layer Height/ Width [mm]	3D Printing Flow Rate [%]	Print speed [mm/s]	Quality
100 + glue	240	0.6/0.8	120	20	Good
100 + glue	250	0.6/0.6	115	25	Good, minor splitting
100 + glue	240	0.8/1.2	115	25	Good

Table 6: Ideal filament and 3D print settings for HIPS

Figure 25: Upcycled filament and 3D test print collection



05

PARTICIPATORY RESEARCH

5.1

SCHOOL 01

OBSERVATION

Two days were spent on-site at a co-educational school in Auckland.

On the first day, the author was introduced to various students that were working collectively to prepare for a trip to Tonga in the upcoming weeks. The purpose of this trip was for students to showcase their prototype and proposal for a heart rate monitor designed for third world countries. The students had been working to produce a clamp made from recycled plastic waste that could be replicated easily and affordably. On the day of the visit, one student had been tasked with creating the mould to form the clamp. After quickly sketching out a few ideas, the shape was then drawn out onto a block of wood sourced from the workshop. After some deliberating and guidance from the workshop technician, the student soon had a quick prototype made for the mould. Shredded HDPE supplied from Fonterra was stuffed into the cavity and placed in the benchtop oven, at a temperature previously used to experiment with melting the plastic.

During a math lesson the author was also introduced by the teacher to a group of about 15 students. After explaining the research, a collection of 3D prints the author had previously made using plastic waste were shown to the class. Students when prompted, were able to identify some of the plastic types, particularly the deep blue - made from Tip Top ice cream containers. All 3D prints were passed around the class, with students showing interest in both the malleable prints such as springy bracelets and a skipping rope. This class had just started their latest project focusing on creating awareness around recycling, with the students looking at different ways to do this through gamification and posters.

On the second day a team of six students had invited a small group of students from Rotorua to participate in a student-led design sprint. The author joined this group and also took part as a participant. The overarching question leading the design sprint was 'What makes a good project?'. Working collectively to manage their first design sprint as a group, each student within the team had their own assigned role. An initial icebreaker was followed by a range of activities that students were using to engage participants and in turn gain insight into what the participants believed makes a good project.

Participation in these activities made it evident that the students were highly capable of using technology to create outputs which are not only creative, but also innovative and useful. The author was impressed by the level of responsibility exemplified by the students in their work, and how they worked together as a team to support each other in their learning and development. There was strong interest in physical models, with students being particularly engaged when looking at the 3D models shown in class.

PHYSICAL LAYOUT

The school learning areas were devised by subject focus, each area was large and open with smaller rooms for more focused group work. Groups of about 80 students would start their subject lesson together, then break off into their smaller assigned groups each with a teacher in charge. Within each group, self-directed learning and student-led initiatives were strongly encouraged and students would choose to do what they found interesting and motivating.

STUDENT ENGAGEMENT

Students engage in various projects that interest them and choose to work either independently or as a group to accomplish their projects to the best of their ability. After discussing their project idea with their teachers, students are free to establish and enact their projects. Although students are given the freedom to determine the projects they undertake, the majority of them appeared engaged in projects encompassing different aspects of sustainability, while focusing on their particular interests. It was encouraging to see some students expressing an interest in future-focused ideas which drive their projects, enabling them to learn and develop a range of skills to support communities. This shows given the freedom to choose their own projects, students can be self-motivated and appear to have a natural tendency to find unique ways to engage with topics such as sustainability.

3D PRINTING

The school's 3D printers were located in a small glass room, in the middle of an open planned classroom space. There were two Makerbots (a Replicator + and a Replicator mini +), as well as a range of coloured PLA filaments available for students to use. Some students had been previously introduced to 3D printing, however, the 3D printers at the school sat idle. They had not been used for months due to unknown technical difficulties and a technician was required in order to fix them.

INTERPRETATION

Due to schools around New Zealand having a wide variety of layouts, structures and dynamics an educational school programme would have to be adaptable to fit into a wide variety of teaching methods. A school such as School 01 has a self-directed learning approach, which would allow for the easy integration of an education programme. However, most schools in New Zealand have more rigid structures. There would have to be consideration put into how the programme could fit within the timeframe of the teaching of the standard curriculum. Students also demonstrated the ability to work efficiently and supportively as part of a group, in particular when they undertook a design sprint in a small team. Integrating group work as a part of the programme could benefit student engagement, as they could be supported by their peers in their learning. The teaching strategy of self-directed learning used by School 01 was evidently successful in engaging students with topics such as sustainability. While this strategy is not commonly used among New Zealand schools, integrating elements of self-directed learning into an education programme may be beneficial in getting students to meaningfully engage with sustainable topics. Furthermore, the technical problems with the printers at School 01 highlights the need for schools to be able to easily maintain and repair 3D printers, if they are to be regularly used by students within an education programme.

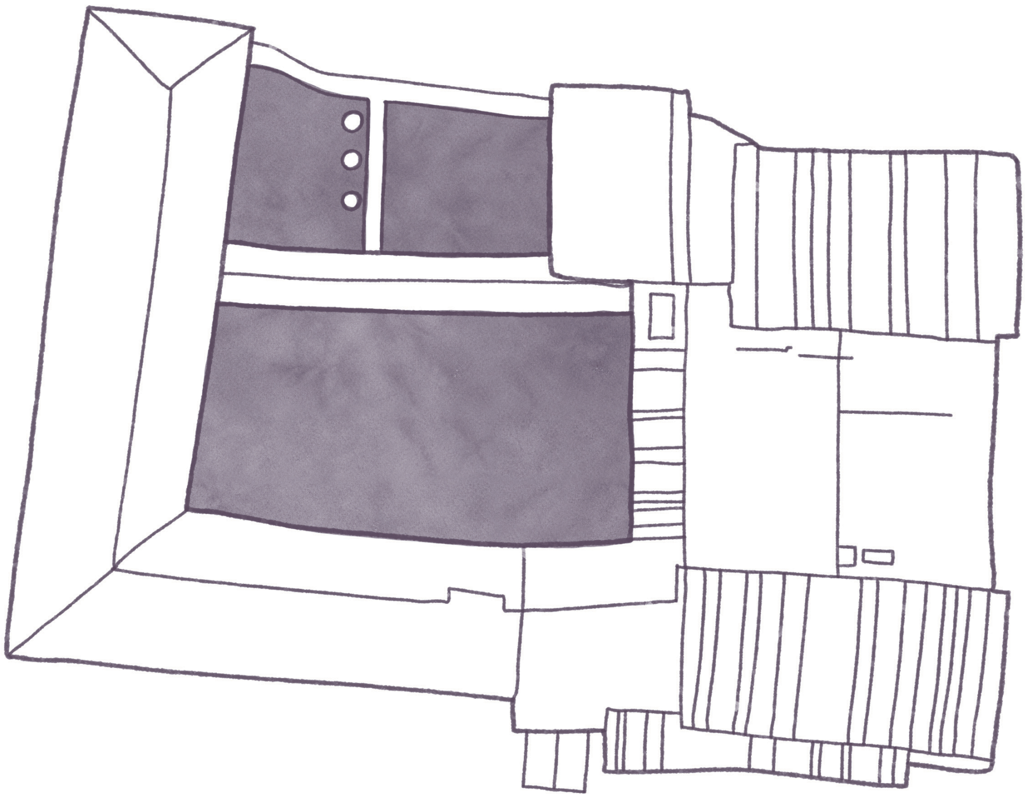


Figure 26: Bird's eye view representation of School 01

5.2

SCHOOL 02

FOCUS GROUP

The author was invited to School 02 to spend the afternoon talking to two different classes about the research. A presentation was prepared for the students that briefly introduced the three themes of plastic waste, upcycling and 3D printing. After each theme was explained, an interactive activity was used in an attempt to further engage the students and gain insight into students' attitudes, perceptions and opinions on the three themes. The teacher in charge of these classes was present and observed the presentation, only speaking up to assist with organising students with each of the activities. All presentation material can be found in Appendix A.

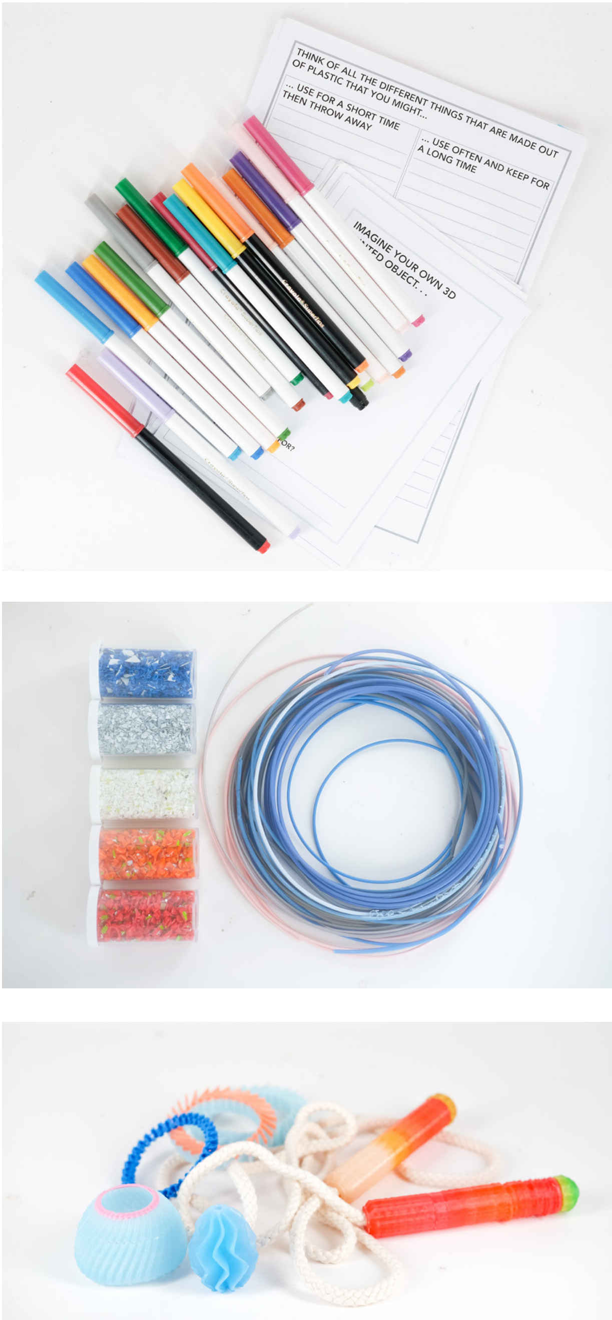
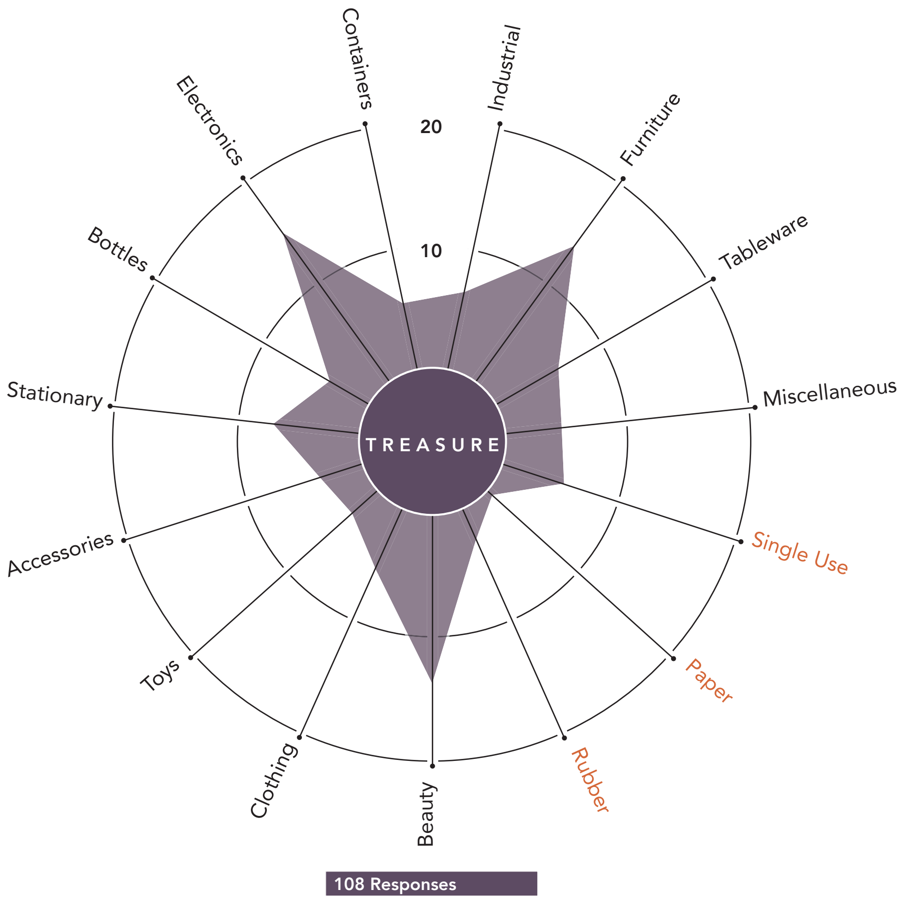


Figure 27: Activity print outs, plastic materials and upcycled 3D prints

THEME 01 - PLASTIC WASTE

Plastic waste was introduced to students as the first theme. Students were informed of how in current society we rely on plastic for a lot of things and how it can be beneficial to our everyday lives. Following this, the challenges and consequences of our current relationship with plastic was revealed through imagery of plastic pollution in different contexts. Emphasis was put on the need for more sustainable solutions before leading into the next theme.

Following the introduction to plastic waste, students were assigned to random groups - a method recommended by the teacher of the class. Groups were tasked with completing a 'List' activity that asked students to think of all the different things made from plastic which they might either 'use for a short time then throw away,' or 'use often and keep for a long time.' This resulted in two separate lists from each group of students. As students worked collectively to fill out the lists to the best of their ability, the author talked to each group and provided support where necessary. Further clarity was needed for some students, it was found that providing simple examples by looking around the room helped prompt students to start discovering their own ideas. Students' responses have been combined and represented in Figure 28.



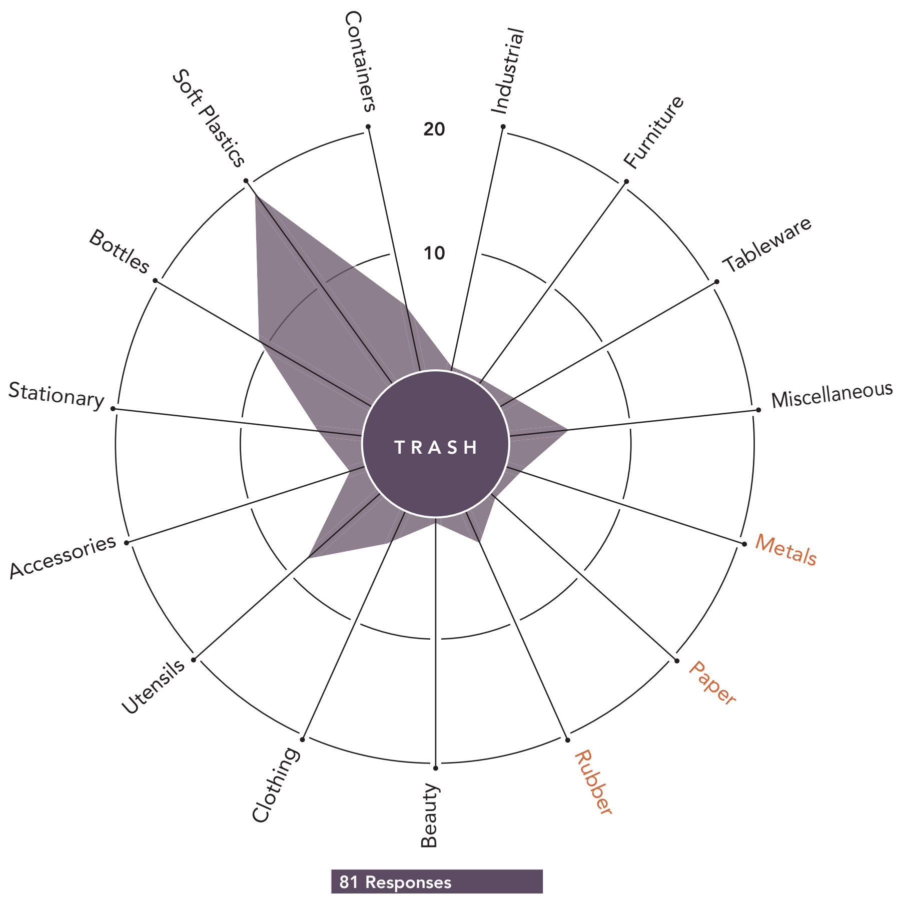


Figure 28: Graph showing students combined responses to the 'List' activity

THEME 02 - UPCYCLING

To introduce upcycling, a range of global and local upcycling initiatives were presented to inspire and show students the many possibilities for upcycling plastic waste into more useful, longer lasting products. Images and physical examples of plastic throughout the filament making process were then presented to students as a more thorough example of upcycling. To stress the importance of the need to properly wash plastic, two containers of milk caps were passed around. Students were asked to sniff the contents and guess as to which had and had not been thoroughly cleaned. They were initially hesitant to sniff either container, but were quickly excited and determined to see if they could handle sniffing the uncleaned caps. A selection of colourful plastic granules was then shown along with their corresponding 3D printing filaments. Students were surprised to learn that the granules had come from plastic such as the bottle caps.

THEME 03 - 3D PRINTING

Finally, for the 3D printing theme, students watched a short video and were shown various images of 3D printing being used within recognisable industry and everyday applications.

Only one of the two groups completed the final 'Imagine' activity due to time constraints. Students were asked to imagine their own 3D printed object. Prompts at the bottom of the activity page asked what their object would be used for and who would use it. Coloured pens were handed out to students and within five minutes most students had produced a quick simple sketch of what they would like to 3D print. The majority of students' drawings were inspired by either their lists or something they could see within eyesight. A group of three friends each drew a Dragon Ball Z character, and revealed a competitive aspect to their drawings when asking the author's preference. Other drawings included a hand, shoes, wheels and glasses.

To complete the presentation a collection of 3D printed objects was shown to students as an interactive exhibition. These consisted of a variety of objects that had been made by students and staff at Victoria University in previous years, as well as a range of upcycled 3D prints the author had previously made. The exhibition was interesting for students, as they were able to pick up each of the prints to analyse them in an attempt to identify the use of each of the models.

INTERPRETATION

Findings from both the presentation and list activities indicated that more education is needed for students to be able to recognise and differentiate different plastic types. If students were going to gather their own plastic waste for upcycling, this would have to be a key focus of the programme to avoid the contamination of recyclables. Comparing findings between School 01 and School 02 demonstrated that schools can differ in regards to their experience with sustainable topics. This would need to be considered in the development of the programme, to ensure that it is being taught in a way that allows a variety of schools around New Zealand to engage easily and meaningfully. Observations at School 02 also demonstrated keen student interest in physical models and objects, exemplifying the potential for engaging students through tangible, 3D printed outputs.

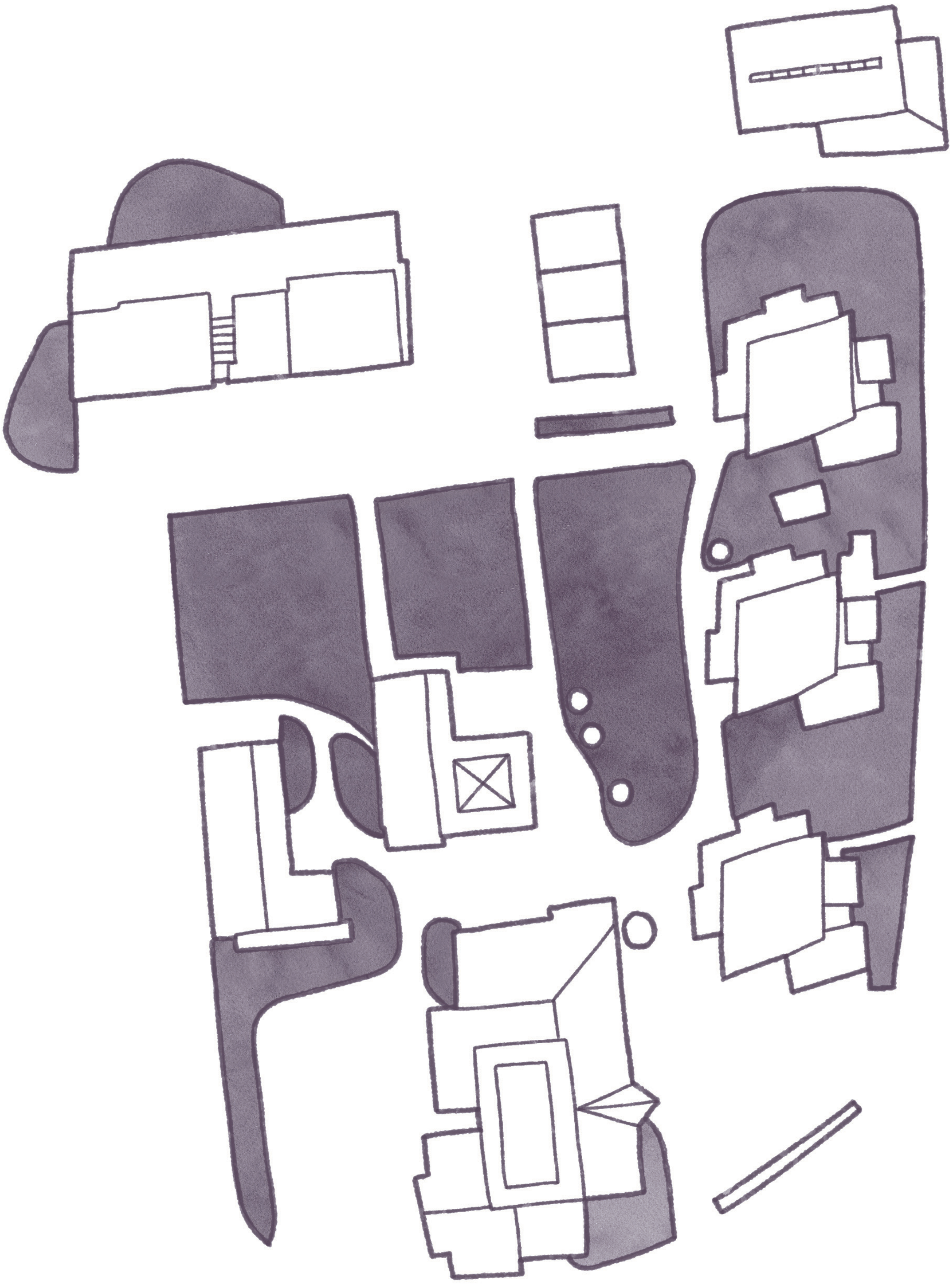


Figure 29: Bird's eye view representation of School 02

5.3

SCHOOL 03

A total of 73 year 8 design technology students were given access to a series of online lessons and activities through their teacher, designed for students from School 03 to complete while working from home.

QUESTIONNAIRE

In total 73 questionnaires were completed by year 8 students at School 03, focused on their thoughts and experiences regarding 3D printing. Many of the following answers have been slightly reworded where appropriate and represented in bar and polar graphs. These revisions have been carefully made to express opinions and ideas to the effect of the original written answers. Many responses to the questions were relatively identical despite being provided by different students. Therefore, for the sake of simplicity, discretion has been used to combine some responses together, or to omit some in favour of similar ones that are more suitable. Of the 73 responses it is important to note that some may be double ups from the same students. There was no limit to how many times the questionnaire could be submitted and some students may have wanted to revise/re-answer some of the questions.

Q1. Have you done any 3D printing?

Only 21 of the 73 participants had done 3D printing before. This shows that although some students had been introduced and had access to 3D printing, the vast majority had not. Some students made comments that they had designed a model suitable for 3D printing using TinkerCAD software. However, it had not physically been 3D printed therefore they answered 'No' to the question, despite having some experience with the software.

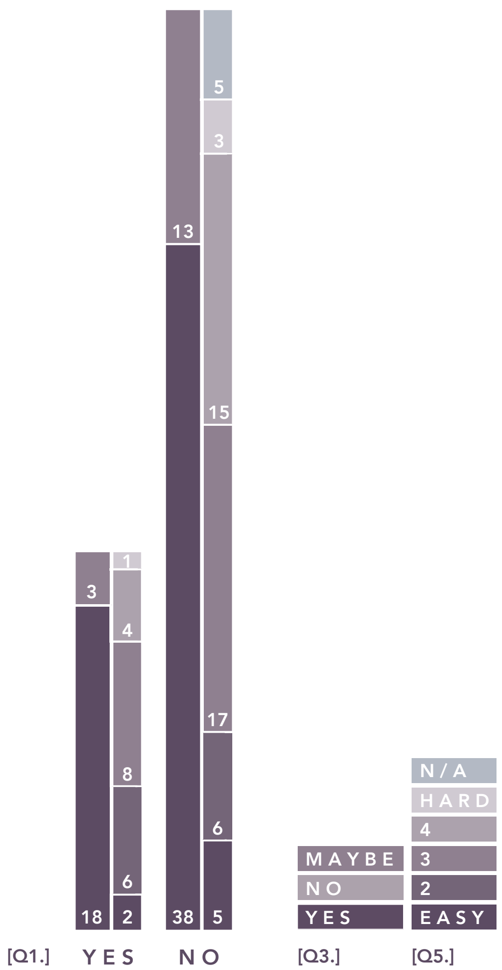


Figure 30: Graph comparing students perceptions of 3D printing who have and have not 3D printed before

Q2. If yes, what did you print? If no, what would you want to 3D print?

The graph shows a comparison between what has been printed by students who have previously done 3D printing, and what students who have not done 3D printing would like to 3D print (Figure 31).

Most ideas were not overly ambitious and would be relatively achievable using 3D printing technology. The only suggestions slightly out of range would be the few requests to 3D print a car, this would most likely not be achievable unless it was a small scale model. A common interest amongst the students was gaming, there was significant interest in adapting and customising their existing consoles and creating gaming accessories through 3D printing. Another common theme was the desire to create characters, mini figures and different toys, mostly from TV shows and video games. The majority of these were static objects based upon existing designs from major franchises such as Pokémon and Star Wars.

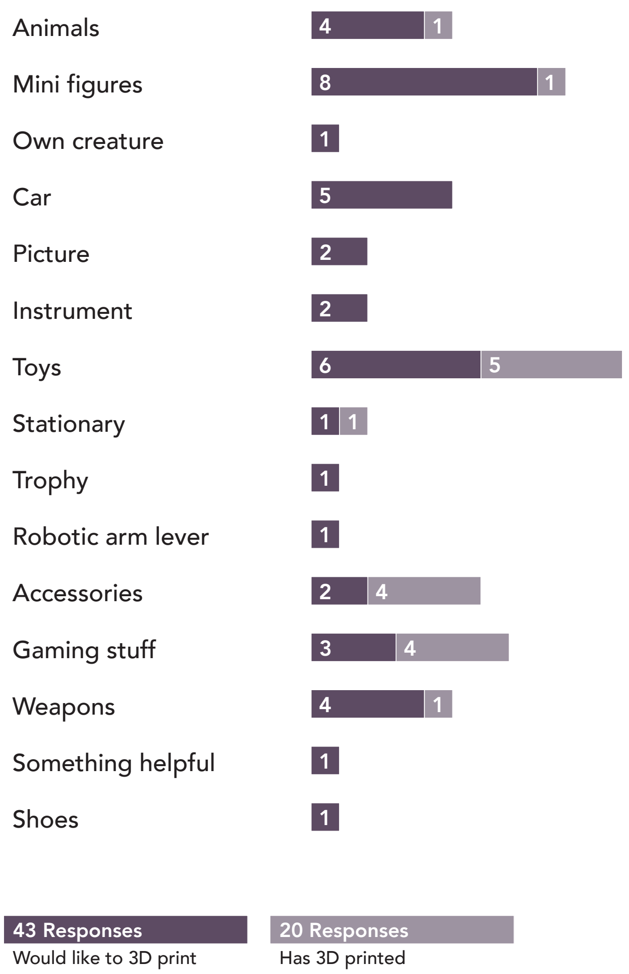


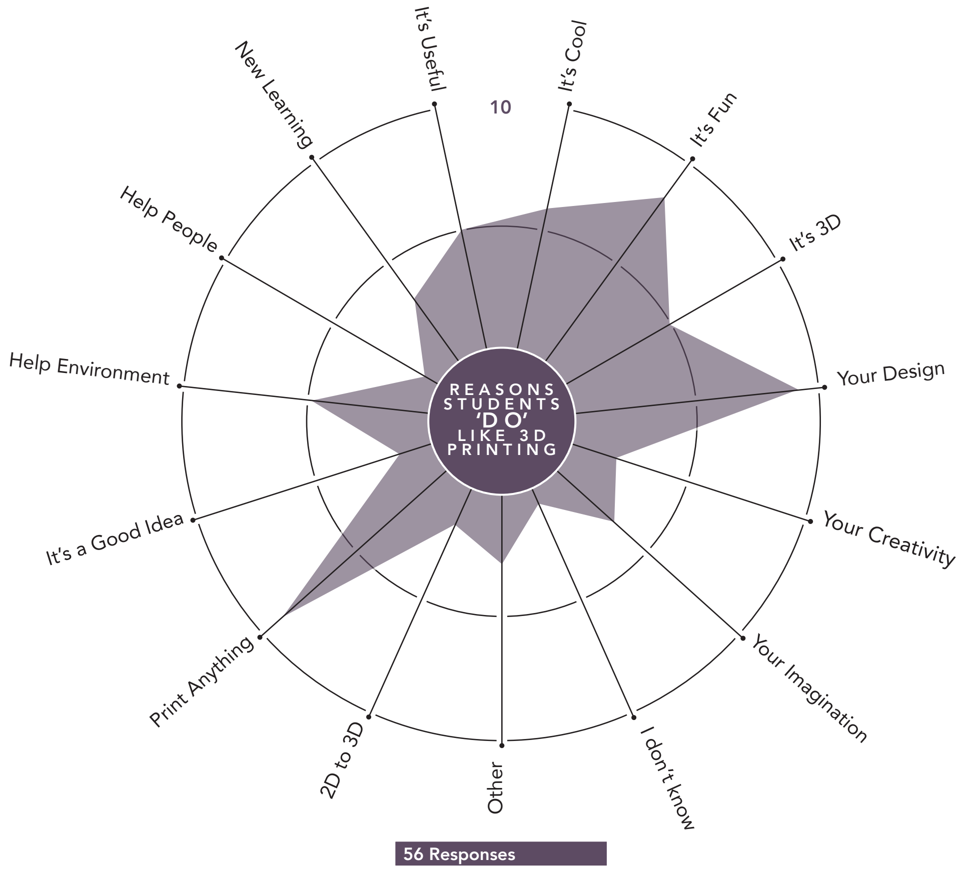
Figure 31: Graph comparing what students *have* and *would like* to 3D print

Q3. Do you like the idea of 3D printing? Q4. Why?

It was clear that the majority of students were mostly interested in the concept of 3D printing, regardless of their level of experience. None of the students answered 'No' to this question, with only 16 of the total answering 'Maybe'. The most popular reasons for students liking 3D printing were that 'It's cool and fun', 'It's 3D' and 'You can print anything you want'.

Q5. How difficult would you rate 3D printing?

For this question, students were prompted with a scale graph with a range from one to five, with five being very difficult, and one being very easy. Of the students who had participated in 3D printing before, the majority had found it to be two or three out of five on the difficulty scale. The students who had not done 3D printing had a slightly different perception, believing it was more difficult with an average rating of four on the scale. This shows that as students become more accustomed to using 3D printing, their perceptions and confidence regarding the use of the technology has the potential to develop substantially.



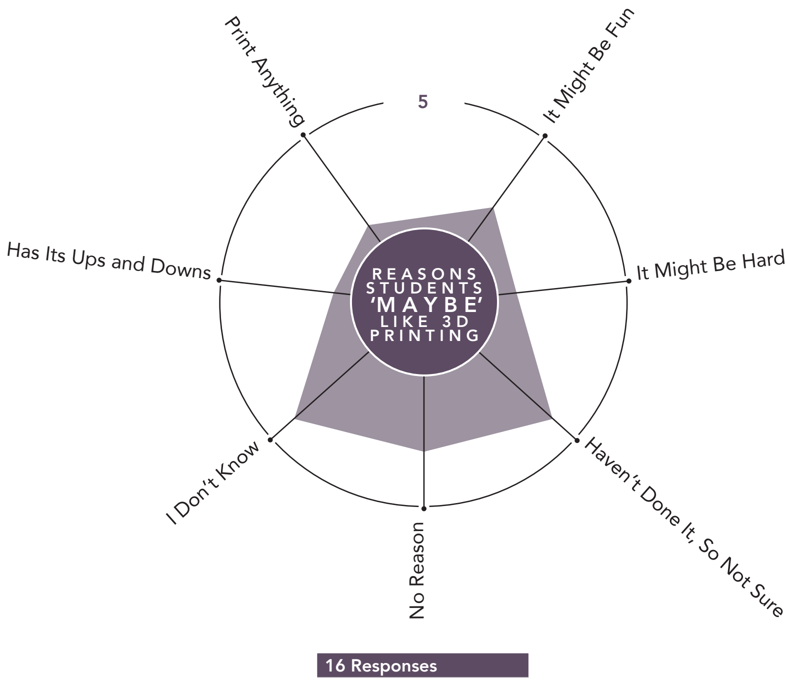


Figure 32: Graphs showing students combined responses for why the *do*/*maybe* like 3D printing

Q6. List anything you can think of that is good about 3D printing.

Students showed a strong interest in using 3D printing to create physical, tangible objects, with this being the top answer regarding what they liked about 3D printing. Another strong theme that arose from this question was the freedom to create anything you want, with students indicating a keen interest in creating, designing and 3D printing their own customised designs.

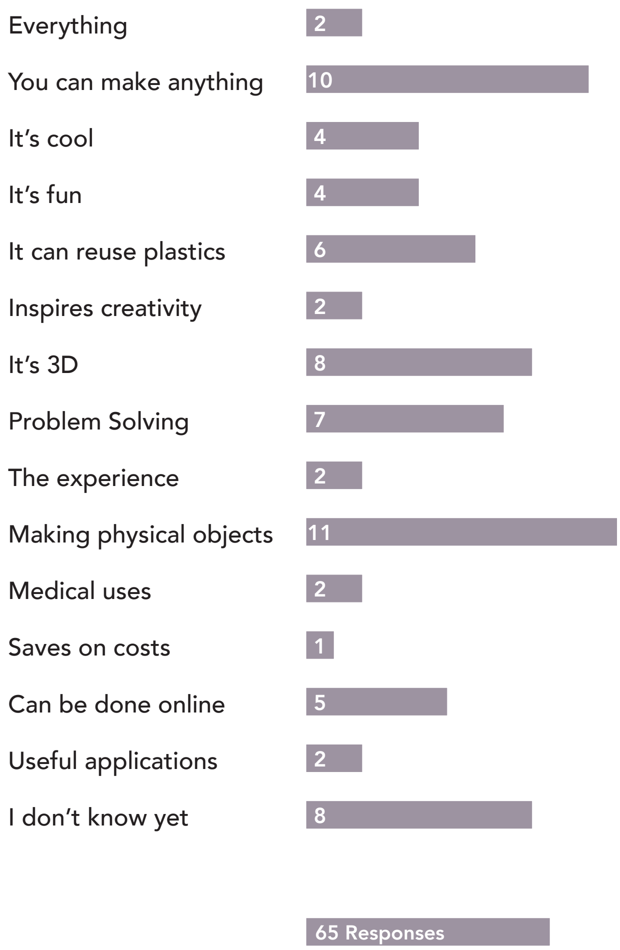


Figure 33: Graph representing students responses to what they think is good about 3D printing

Q7. List anything you can think of that is not so good about 3D printing.

Students were able to identify some disadvantages of 3D printing technology such as 'It takes a long time', 'It's expensive', and 'It doesn't print correctly.' The most common answers were 'Nothing' or 'I don't know', these responses were both from students who had experience, as well as those who had not.

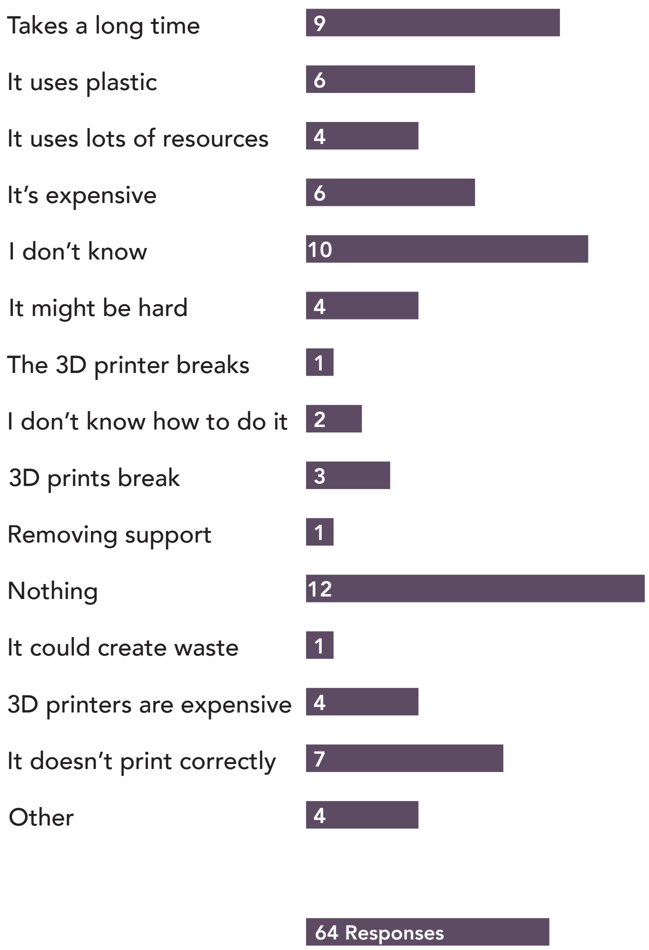


Figure 34: Graph representing students responses to what they think is not so good about 3D printing

Q8. What is the most interesting thing you have seen that is 3D printed?

The most common responses were different types of weapons, cars and toys. There were a few students that had not seen 3D printing or claimed not to have seen anything interesting to do with 3D printing.

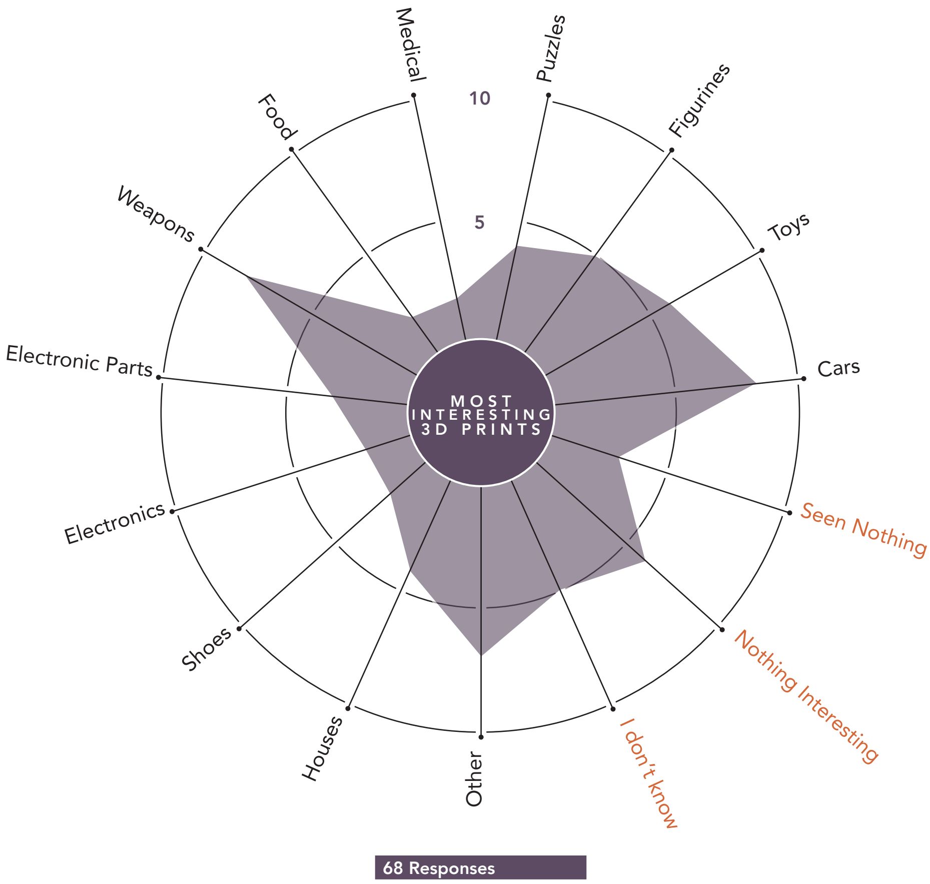


Figure 35: Graph showing students responses to the most interesting 3D printed object they have seen

DAIRY DIARY

The 'Dairy Diary' activity was completed by 10 students, documenting how much plastic waste they generated over a two-week period . The majority of students correctly filled out each of the sections, being able to reference the product details as well as the plastic type. Although only a relatively small number participated in this activity it shows that with some simple guidance and explanation students are able to successfully identify plastic types. Only four different plastic types were identified, polyethylene terephthalate (PET), HDPE, polypropylene (PP) and PS. A combined total of students' responses is represented in Figure 36. It is important to note that one student had listed that they used 98 two-litre milk bottles over the course of two weeks, as well as 23 other dairy products. This student's answers have been included, however, it is not known whether this is a correct representation. The results from this activity show that at home, students and their families are using multiple plastic packaging products and have access to dairy waste that could be used in the collection for an educational school programme.

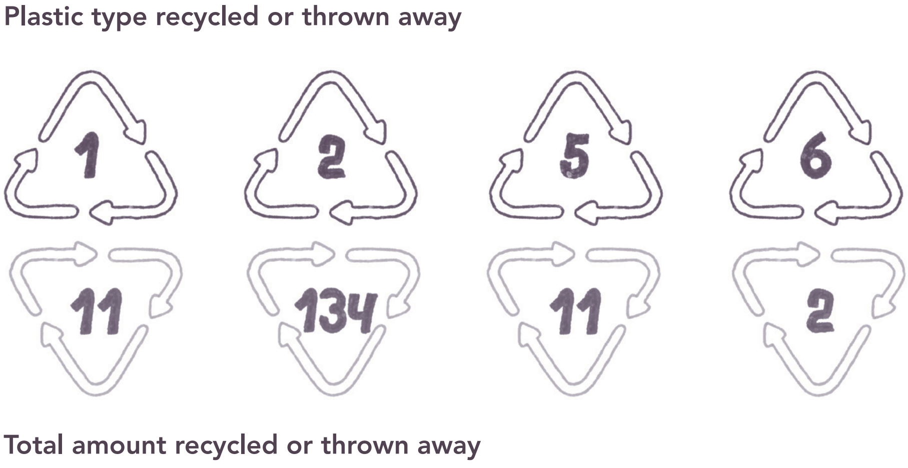


Figure 36: Graphic representation of what plastics were recorded by students in the 'Dairy Diary' activity

COLLECT

A few students participated in the 'Collect' activity which asked students to collect and clean a range of bottle caps from dairy products. Students had asked their teacher if they could also collect caps from other products such as water and juice bottles. As the majority of lids are manufactured using HDPE it was agreed students could collect any plastic caps they could find. Over the two-week period, students and the teacher were able to collect a total of 170 grams of different plastic caps (Figure 37). The caps were all well cleaned, with no smell or visible need for more thorough cleaning. This was successful in demonstrating that students, when prompted, will properly clean plastic waste, helping with the efficiency of sending plastic in for processing into filament. Although the amount collected was small, it was sufficient to be able to produce a small roll of filament. A few weeks after the initial collection was received, the author was contacted by the teacher to say students had continued to collect and clean plastic caps. It was encouraging to know that students were motivated and intrigued by the activity of collecting bottle caps, resulting in them continuing to take time to participate unprompted.

Figure 37: School 03 bottle cap collection

DRAW

A total of 37 drawings were received from students in response to the 'Draw' activity. This activity asked students to think about and draw something they would like to 3D print using upcycled plastic. Many of the drawings were visual representations from students' original response to the question 'What would you like to 3D print?' in the questionnaire. The most commonly drawn design (appearing 3 times) was a product called Kontrol Freeks. These are customised thumbstick grips which attach to a gaming controller, claiming to provide a better gaming experience. There were also a large amount of both recognisable and imaginary characters and minifigures. All drawings have been republished and represented in figures 38, 39 and 40.

Figure 38: Collection of students' drawings 01

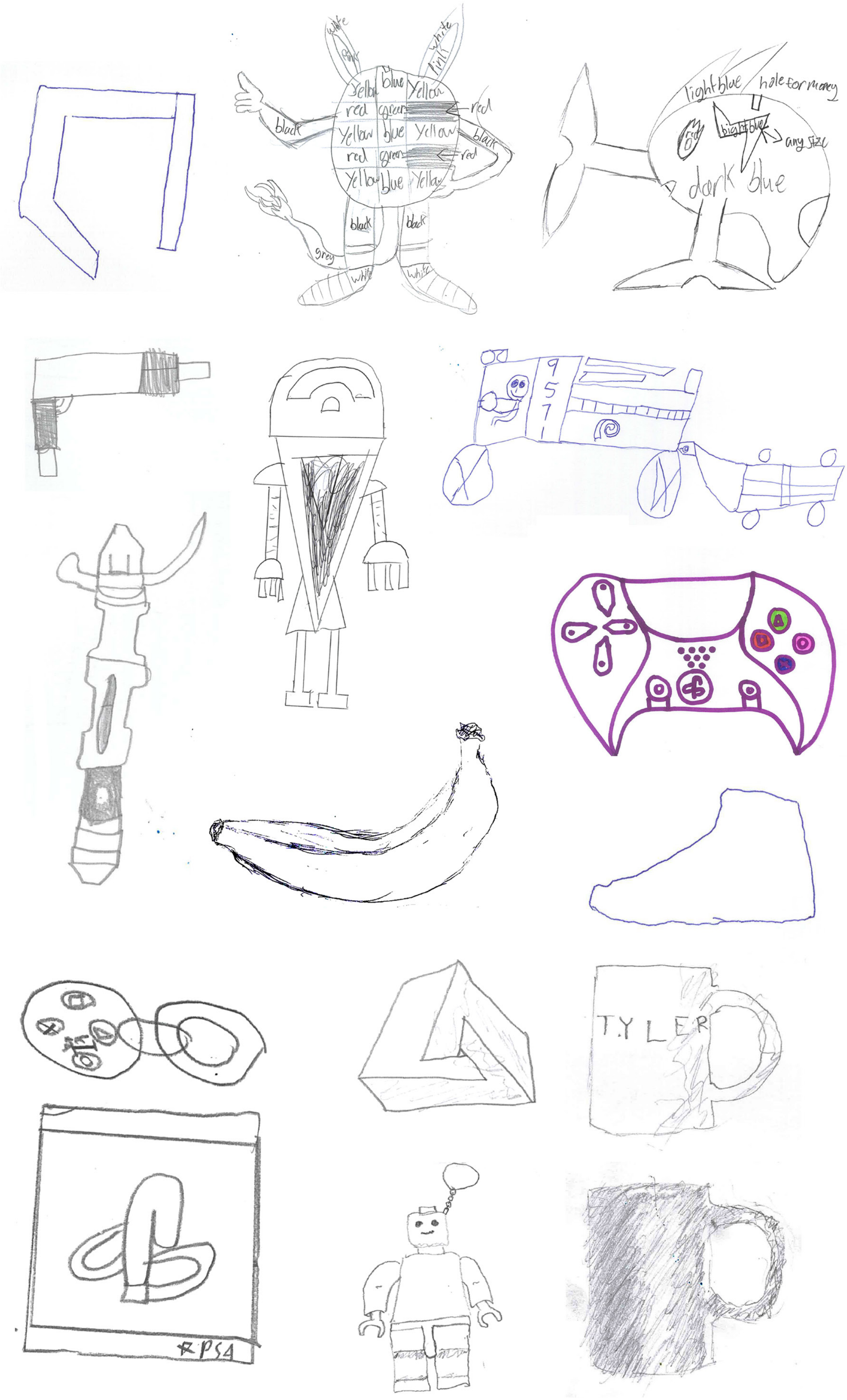


Figure 39: Collection of students' drawings 02

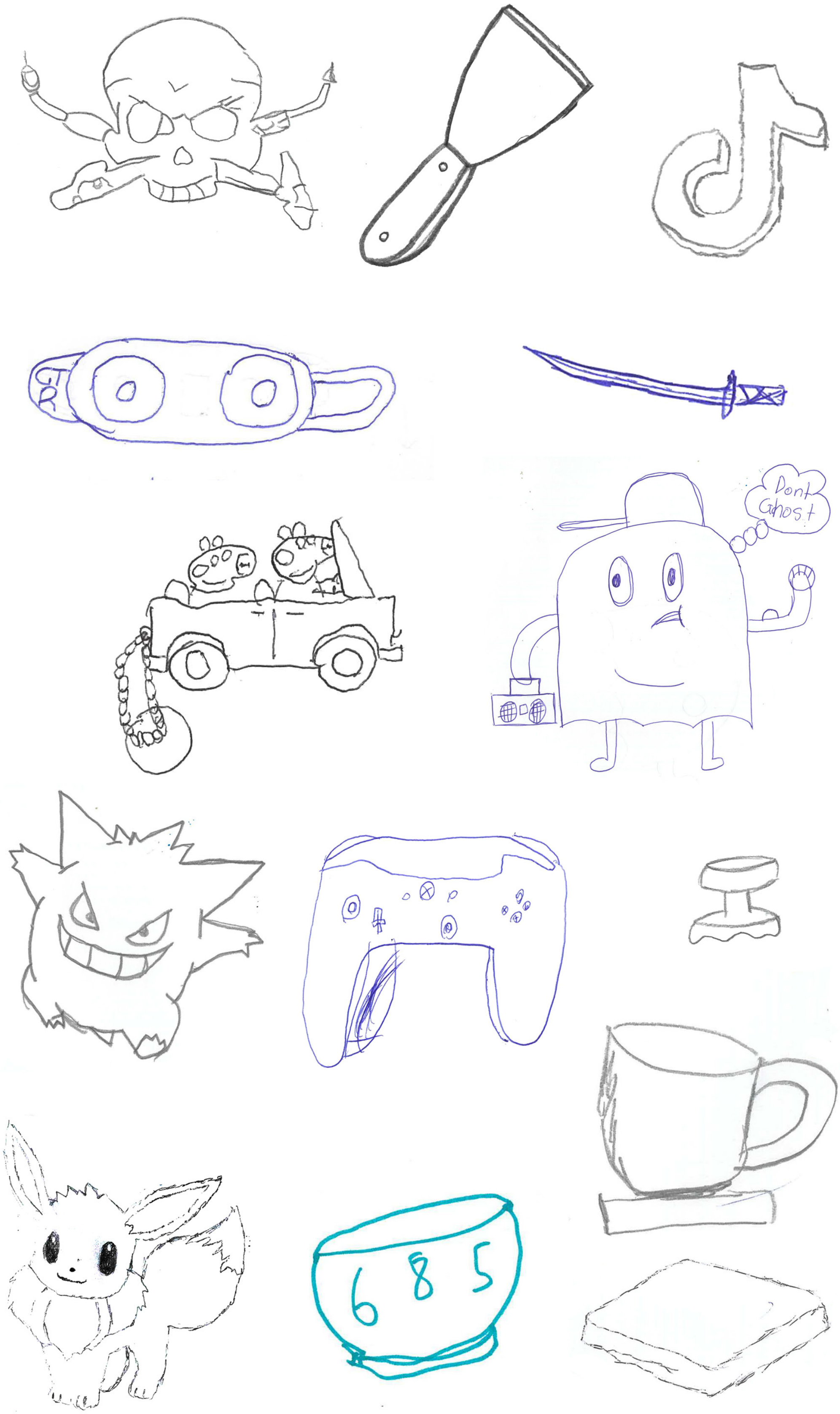


Figure 40: Collection of students' drawings 03

INTERPRETATION

Results from the questionnaire gave an insight into students' thoughts and experiences regarding 3D printing. Although not all students had experience with 3D printing, it was familiar to most of them, and insightful answers to the questions were given by most students.

It was clear that students have high expectations regarding 3D printing and its capability to create a wide variety of outputs, with a significant amount of students referencing ambitious ideas such as houses or cars. There was also some indication that students had experienced disappointment within their own experience with 3D printing. A variety of the students' answers about what they did not like about 3D printing addressed problems such as the printer breaking, taking too long, or not printing correctly. This highlights the need for a focus on printer maintenance, as well as how long objects may take to print, within the design of an education programme. Both the 'Collect' and 'Draw' activities showed students can be actively engaged with sustainable topics through designed activities. The 'Draw' activity also gave clearer indication of what students' expectations were for 3D printing, and demonstrated that students want customised and detailed designs.

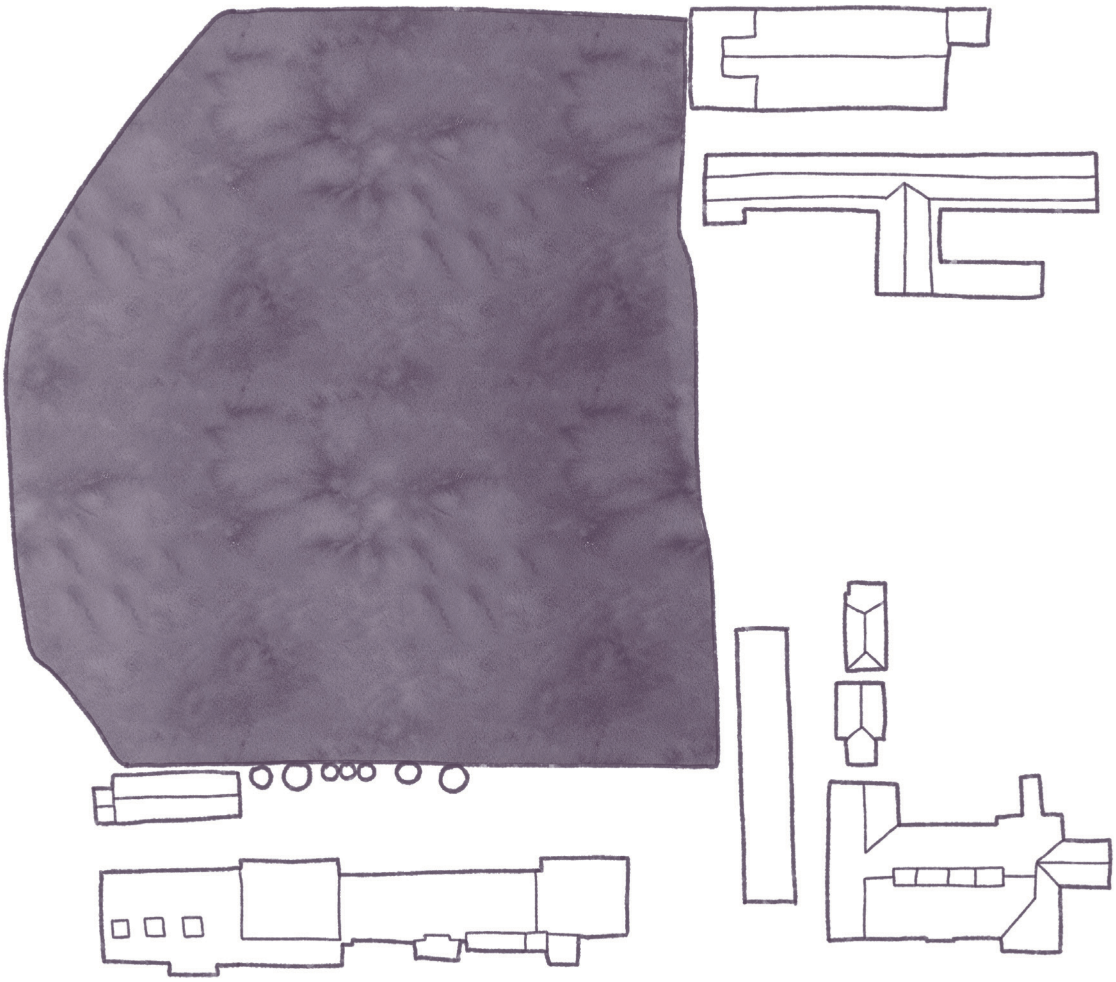


Figure 41: Bird's eye view representation of School 03

5.2

TEACHERS

SURVEY

School waste management, practices and policy.

From the teachers responses to it was evident that each school has integrated some form of recycling into their school waste management plan. None of the schools had specific plans in place to deal with plastic waste, however, it seemed that some were making efforts to limit plastic use and ensure suitable plastic types are being recycled. Although plastic waste is not being dealt with specifically, each of the schools already has a system in place that allows for the collection of other waste such as paper and compost. These pre-existing systems, as well as the interest in recycling shown by teachers, suggest that a collection scheme for plastic waste upcycling within schools would be both feasible and beneficial.

Sustainability and waste management within the curriculum.

The most common tools used to educate children about sustainability and waste management were online resources, as well as the use of outside agencies and the local community. Teachers were positive about student engagement with this learning, and most were positive about their knowledge regarding recycling and their ability to teach sustainable concepts. Examples of sustainable practices and projects within the schools consisted of a huge variety of things such as worm farms, compost bins, wetland restorations, planting trees, and trips to recycling depots.

3D printing within the curriculum.

All schools were involved with teaching students physical crafting methods, however, only one respondent listed using 3D printing within their curriculum. Teachers suggested a variety of subjects that 3D printing could be incorporated into as a learning and making tool, with the most common suggestions being science and technology. They also had a range of ideas as to what students could create using 3D printing, with a focus on objects that could be utilised as educational tools for future student learning. There was low confidence among teachers in their ability to teach 3D printing, which an education programme could help address.

INTERPRETATION

This survey gives an insight into how an upcycled 3D printing education programme could fit within the school environment and curriculum. There is an existing framework for the collection of plastic waste within some schools in New Zealand, this could be adapted and applied to the collection of plastic for 3D printed upcycling. Currently, it seems as though teachers take on individual responsibility for sustainable practices and education, rather than it being an essential part of the curriculum. It was encouraging to see teachers were positive about their knowledge and ability to teach sustainable topics, and their wide variety of ideas for projects indicate collaboration with teachers being a valuable asset. It was interesting that teachers saw science and technology as the subjects most suitable for incorporating with 3D printing projects. Their suggestions for students 3D printing educational tools for future learning provided inspiration for project design concepts in further stages of the research. The low confidence among teachers for teaching 3D printing emphasises the need to make the programme accessible and easy to understand.

SUMMARY

This stage of the research formed specific criteria for an education programme, derived from participatory research methods. The criteria were then used in the development of design concepts to be integrated into the framework of an upcycled 3D printing programme. Observations at School 01 highlighted the need for the programme to be adaptable and consider the issues which occur when 3D printing such as prints failing or taking a long time. Findings at this school also demonstrated the potential for group work and self-directed learning to engage students effectively.

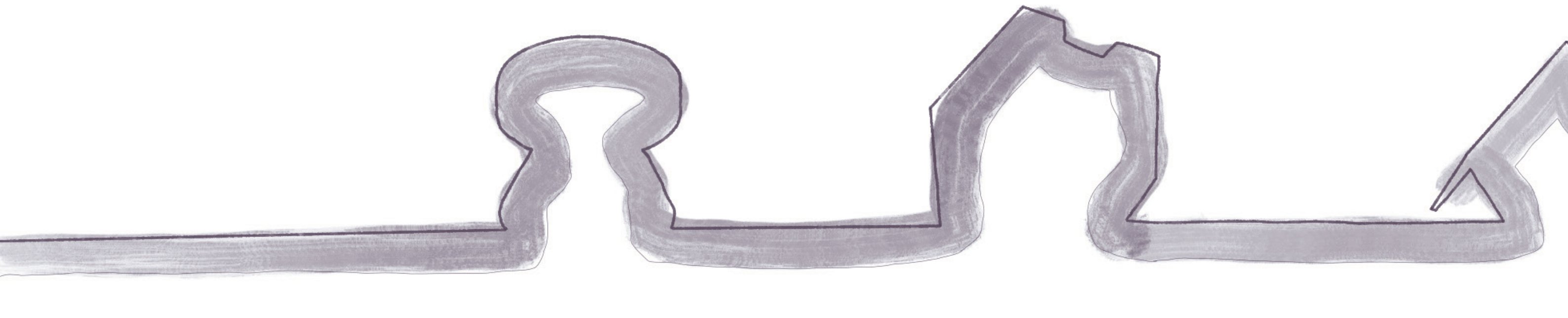
The use of focus groups at School 02 indicated that more education is needed surrounding plastic types for children to differentiate plastic, which they would need to do in order for the education programme to work efficiently. It also emphasised the effectiveness of tangible examples to engage students with 3D printing and upcycling.

Activities at School 03 showed that students can be engaged with sustainable topics through designed activities which give them a specific goal. As well as this, results from the questionnaire highlighted the need to consider how long 3D objects will take to print, as many students mentioned this being a reason they did not enjoy 3D printing. Ideally, 3D printing projects for an education programme would consist of objects which can be printed within an hour.

The teachers survey showed that existing frameworks for recycling could be adopted for 3D printed upcycling. Teachers also suggested that 3D printing could potentially fit into the subjects of science and technology, and that students could create educational tools for future learning. The survey also indicated that the programme would need to be accessible and easy to understand for both students and teachers.

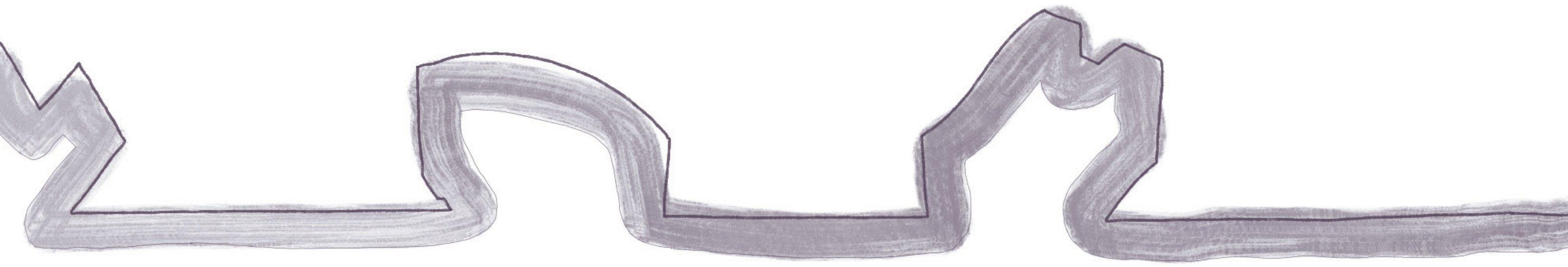
Following the analysis of the participatory research findings, the following criteria were identified as the foundation for the development of a framework for an education programme focused on 3D printing, plastic waste and upcycling:

- **The programme should be adaptable and consider the issues which occur when 3D printing.**
- **Group work and self-directed learning have the potential to engage students effectively.**
- **More education surrounding plastic types is required for students to be able to recognise and differentiate plastic materials.**
- **Tangible examples are engaging for students and encourage questions and open communication.**
- **There needs to be consideration put into how long 3D objects may take to print.**
- **Existing frameworks for recycling within schools could be adopted for 3D printed upcycling.**



06

PROGRAMME PROPOSAL



6.1

THE PROGRAMME

'Plastic in Practice' is a 3D printing education programme which encourages schools around New Zealand to get involved in the upcycling of plastic waste from their local communities. It is adaptable to a wide range of experience levels and subject focuses, with a variety of project outlines which can be easily integrated into classroom learning. Offering tangible engagement with sustainable production technologies of the future, this programme aims to combine 3D printing with plastic waste processing in order to demonstrate sustainable systems in practice to students around New Zealand.

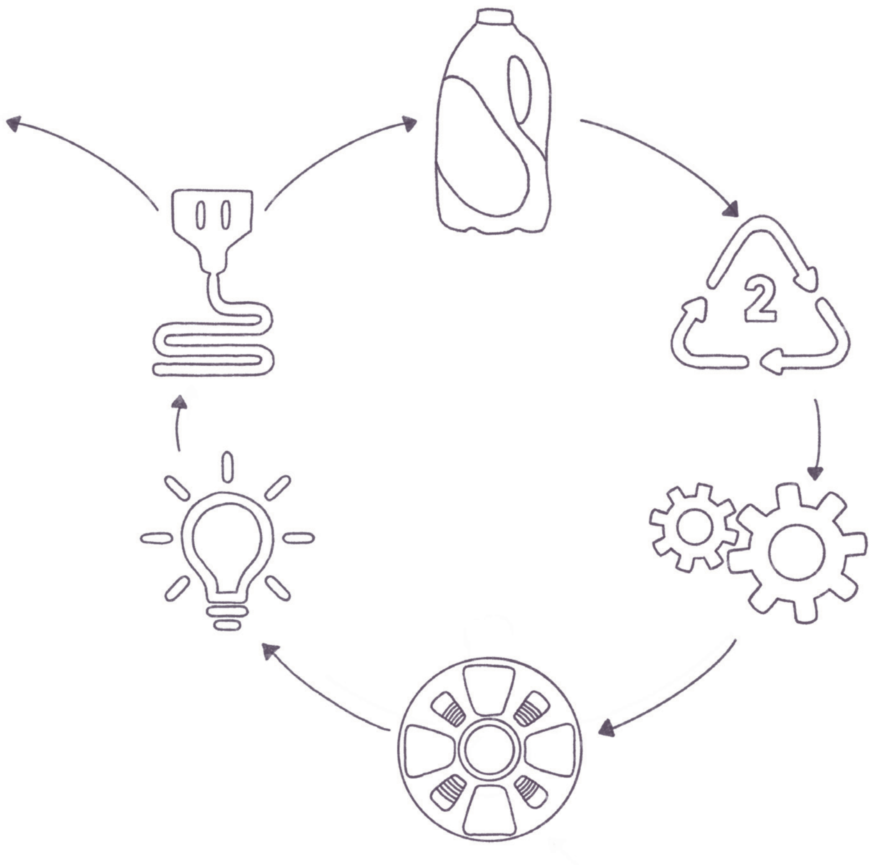


Figure 42: Graphic representation of programme system

THE PLASTIC

Students are encouraged to collect single-use plastic from their homes, schools and local communities, learning about the different plastic types in New Zealand. Before starting the programme, students can be tasked with investigating which plastic types are most accessible to them or which ones they would like to collect. The programme emphasises the importance of cleaning and sorting plastic, with students learning how to properly prepare plastic for upcycling processes. Once collected, cleaned and sorted, the plastic waste is then sent for processing into filament at an offsite plastic processing facility.

Each school that chooses to take part in this programme receives collection point bins, making it easier to take charge of their own plastic waste stream. A bin is supplied for each type of plastic the school decides to collect, which allows for easy sorting and management of different plastic types.

The collection bins are labeled by plastic type, making it easy for students and teachers to dispose of their plastic in the correct bin. The bins are transparent, which allows students to actively see their collection growing, encouraging the continued collection of plastic within the school. When collecting plastic, it is essential that it is cleaned properly to ensure the filament is not contaminated and able to be processed efficiently. The clear bins make it easy to see inside to ensure the plastic is not contaminated with food products, as well as being sorted properly.

Students are encouraged to take responsibility for the maintenance of the collection bins, ensuring they are clean, sorted correctly, and not overflowing. This encourages group work and self-directed learning through students working together, taking the initiative to manage the plastic waste themselves.

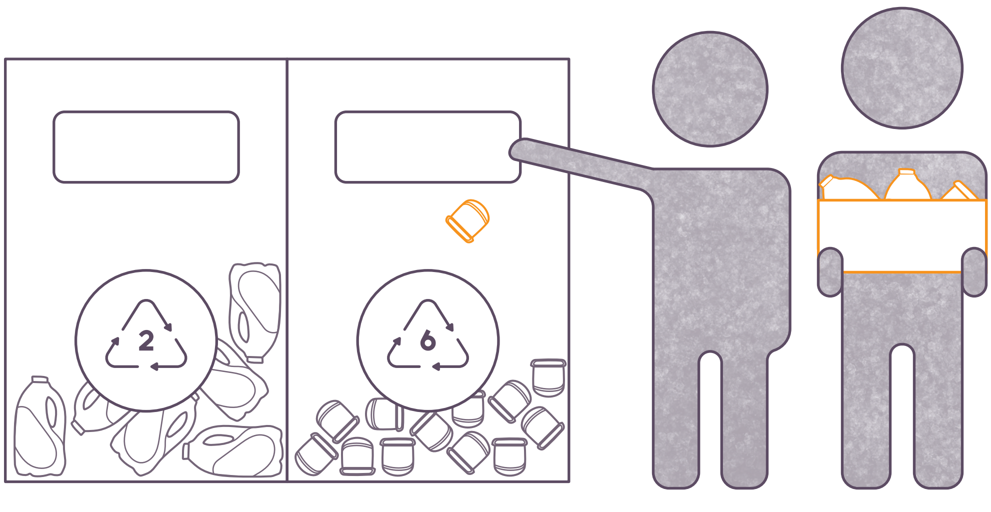


Figure 43: Plastic collection

THE PACKAGE

Once processed, the schools' upcycled filament is then sent back in a package, along with a congratulatory message and included project examples that students could make with their filament. The project example also provides links to dedicated online platforms, as well as other useful 3D printing resources to get schools started with their projects.

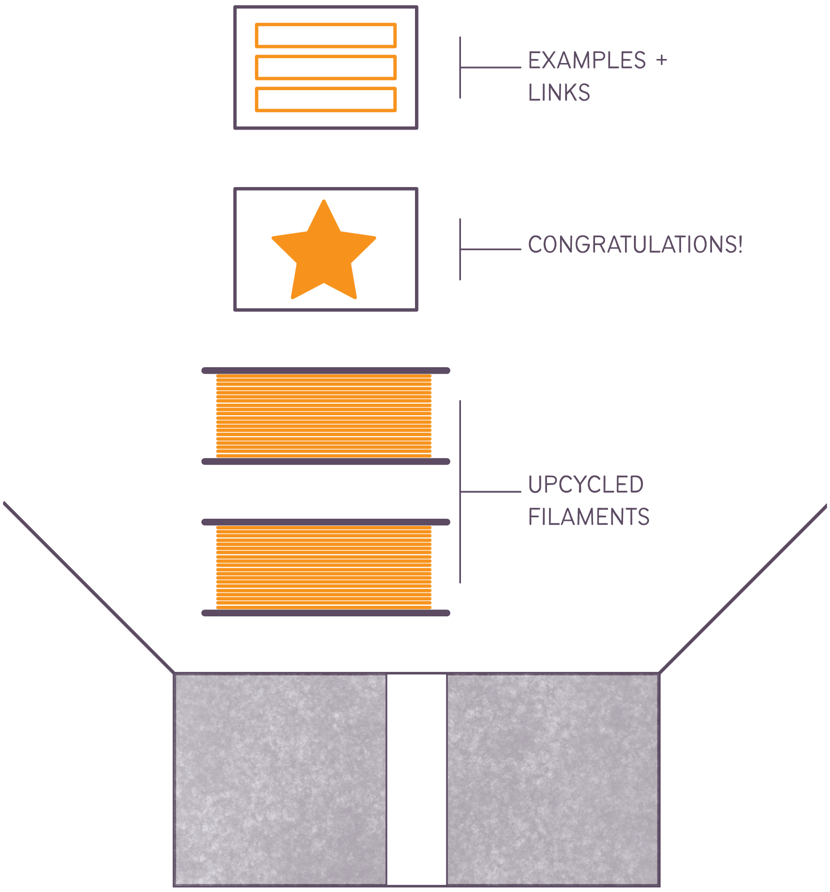


Figure 44: The package

THE PLATFORM

A dedicated online platform gives schools around New Zealand access to project plans as well as recommendations for how to efficiently manage aspects of the programme, such as plastic collection and 3D printing within their school. A basic guide (Figure 46) to plastic types is provided, with recommendations for what kind of plastic waste items students could collect for each type, as well as which types are suitable for 3D printing. Various recommendations for 3D printing are included on the platform, including print settings, quality guides and troubleshooting recommendations. The platform also provides links to useful projects on existing websites such as MakerBot's Thingiverse or Autodesk's Instructables, building a pool of knowledge for schools to collectively draw upon and inspire future projects. Platforms such as Thingiverse allow schools to share their creations, encouraging schools to collaborate and expand upon each others' projects.

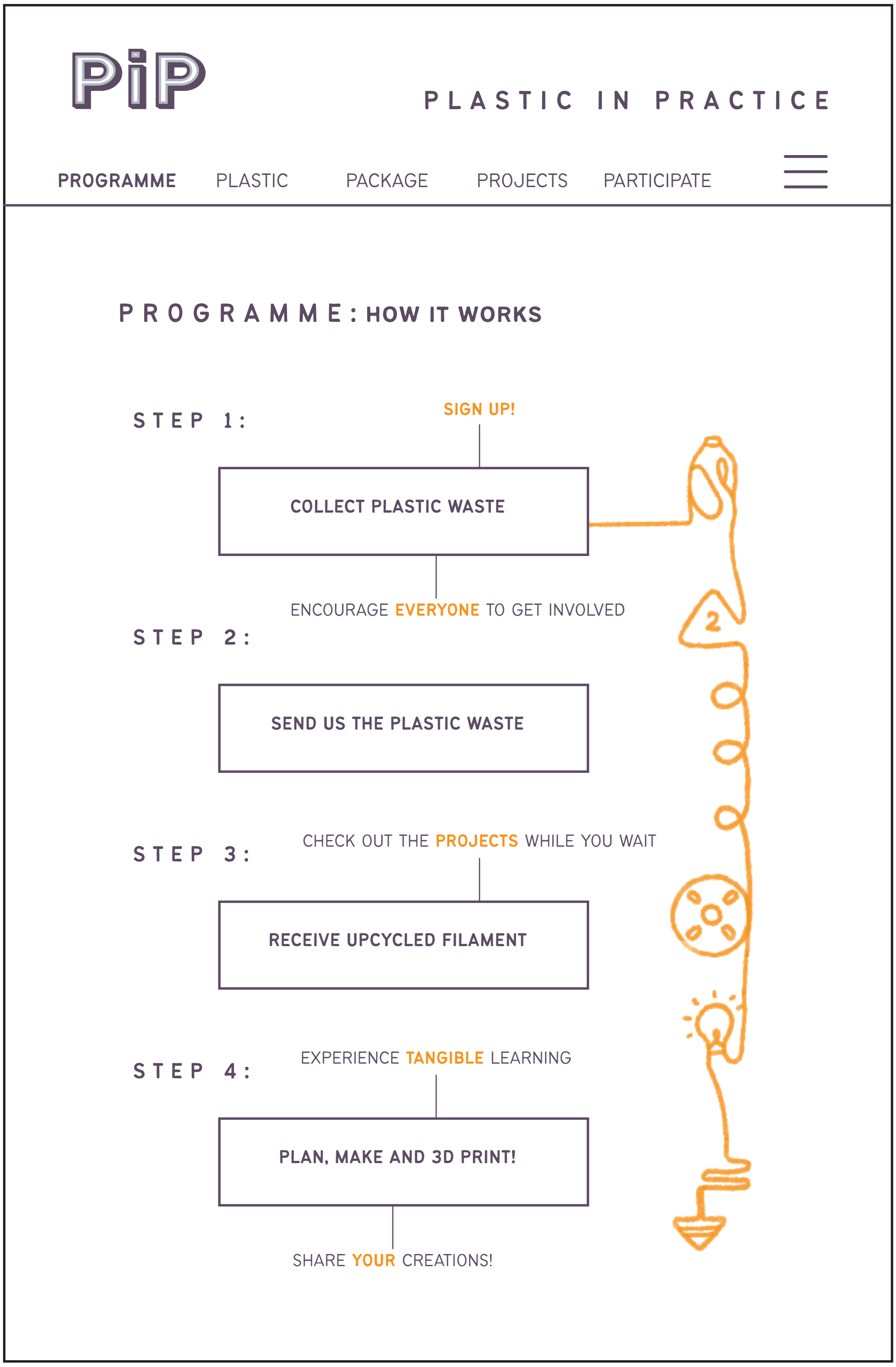


Figure 45: Potential programme digital interface

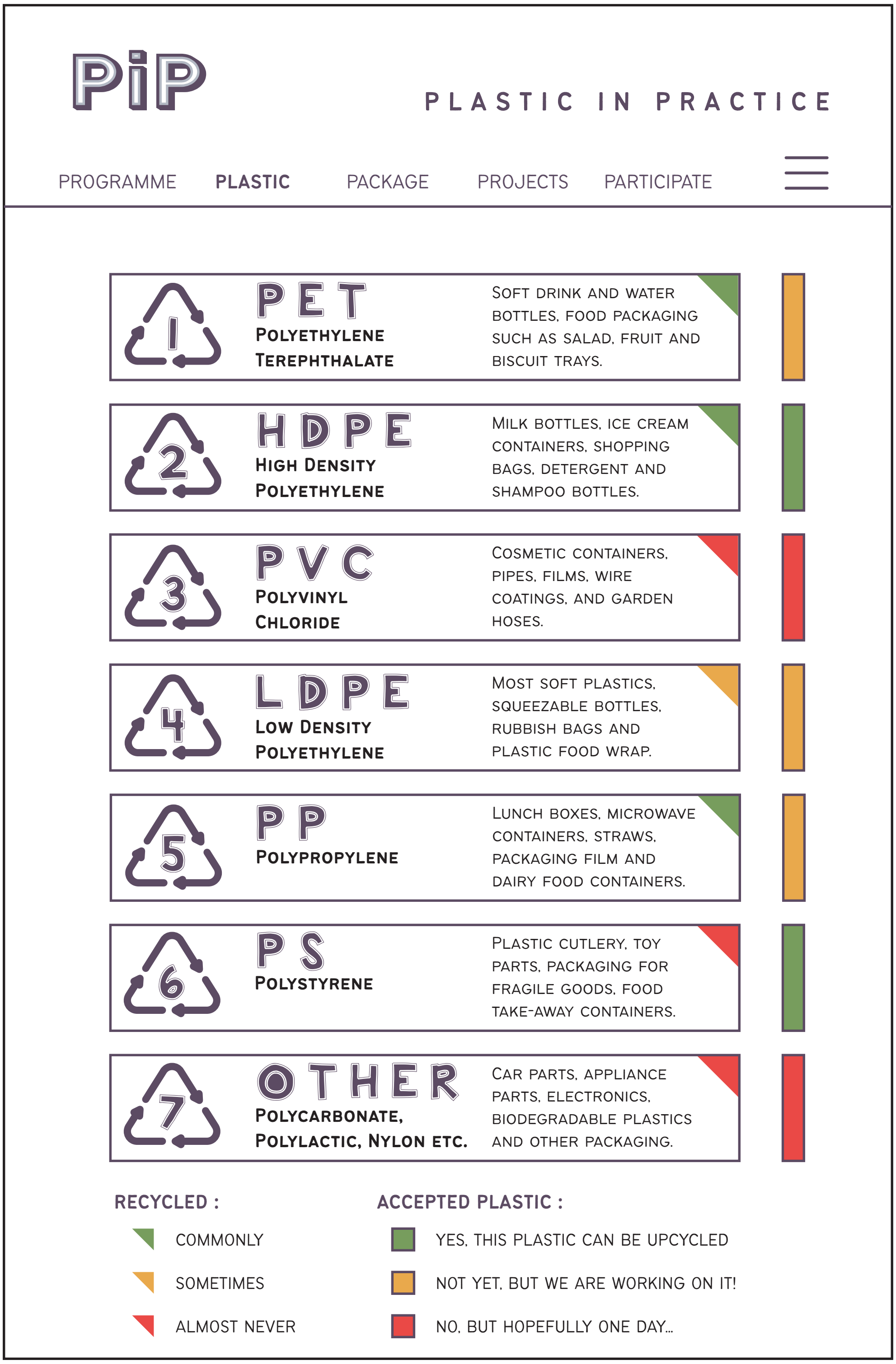


Figure 46: Potential plastic digital interface

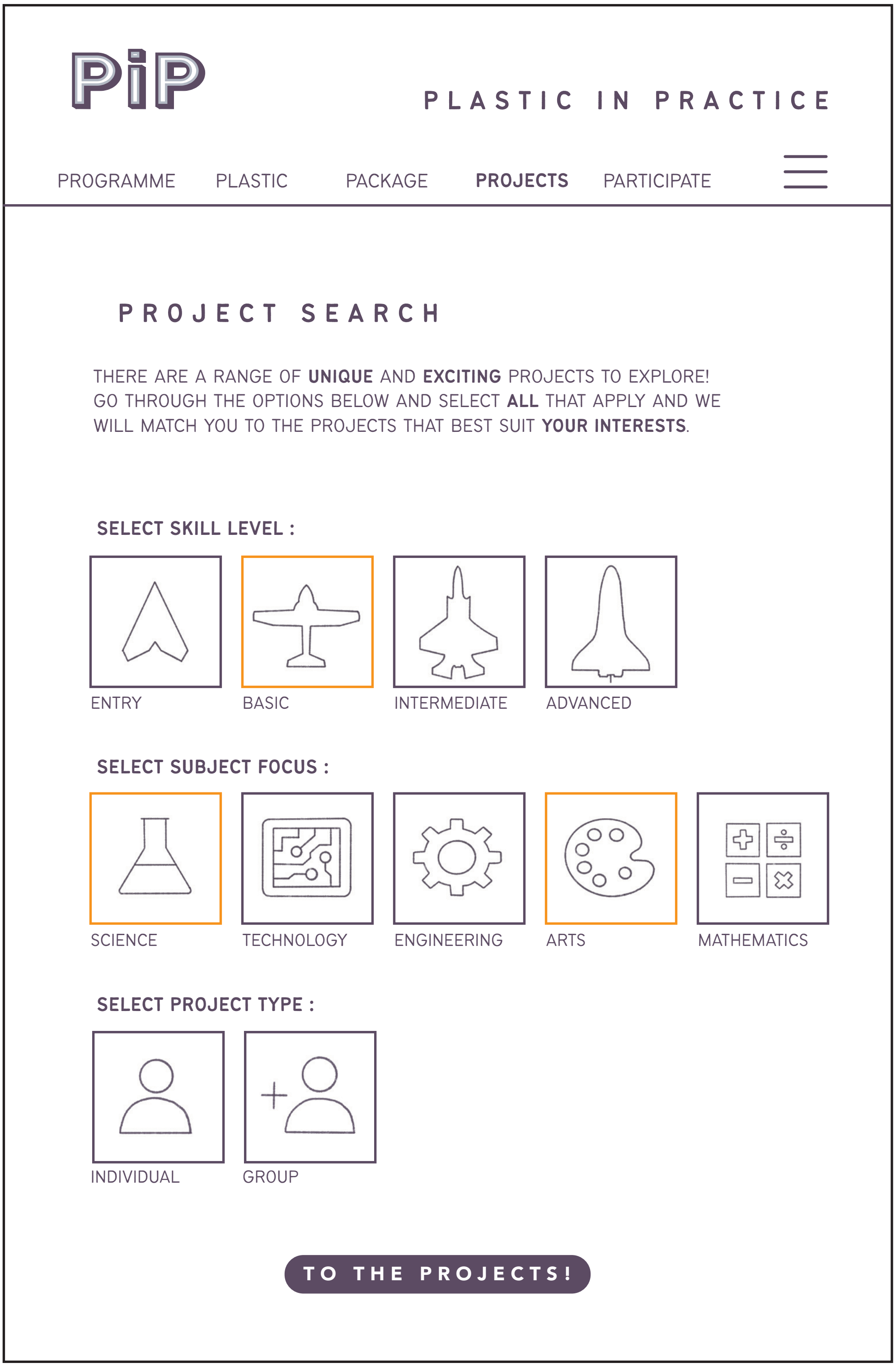


Figure 47: Potential project search digital interface 01

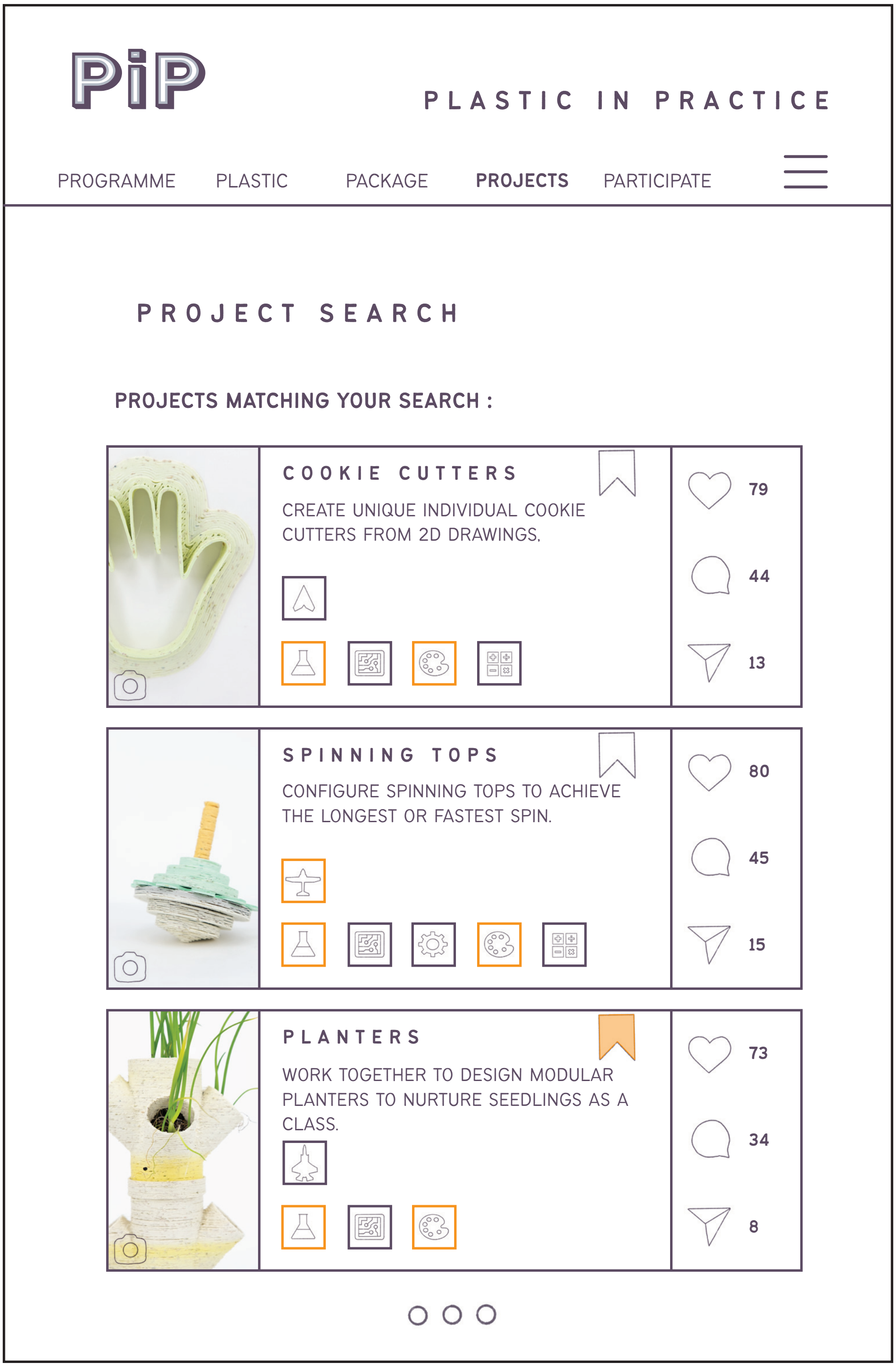


Figure 48: Potential project search digital interface 02

6.2

THE PROJECTS

Research findings indicated that tangible learning was an effective way to engage students with 3D printing and upcycling. Teachers also emphasised the opportunities within 3D printing for students to create educational tools which have a practical learning application. This inspired the development of a series of designed projects which engage students with 3D printing and upcycling. The first project would serve as a simple introduction to 3D printing, with students creating simple 2D drawings which they would then 3D print as cookie cutters. The second and third projects would involve the students making educational tools such as spinning tops and planters, which could then be integrated into Science, Technology, Engineering, Arts and Mathematics (STEAM) learning and have a practical application. These projects would also encourage group work, with students working collaboratively to apply design thinking. In the development of these projects, the time objects would take to 3D print was also considered. Most models are printed as components and could be completed within an hour, addressing the need for 3D printing to be accessible and easy for both students and teachers.

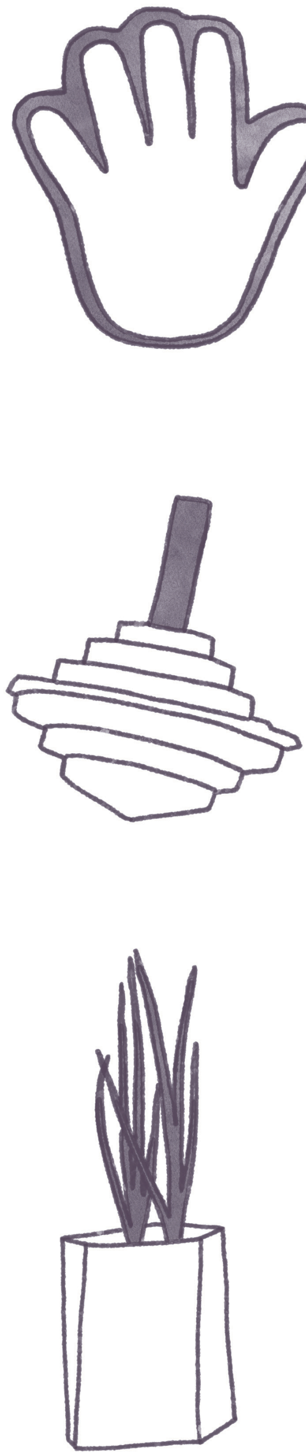


Figure 49: Cookie cutter, spinning top and planter projects

COOKIE CUTTERS

Students' drawings from School 02 inspired the design of the first project, 'Cookie Cutters'. The process of turning 2D drawings into 3D cutters was refined through multiple iterations of 3D models and testing of the 3D printability. For this project, students would be given a brief of drawing something to be made into a cookie cutter. Once the students complete their drawing, they would convert it into outlines using Adobe Illustrator. Students would then measure their drawings to ensure they are the correct size for 3D printing. Once converted to outlines, these drawings could be imported into introductory level CAD software such as TinkerCAD, which converts the outlines into 3D models. This project would be a great way to introduce both students and teachers to 3D printing, as there is minimal 3D modelling involved and the process of converting a drawing to a 3D model is very simple. Additionally, the 3D printing of the cookie cutters would not take very long to complete as they would be small in size, simple in form and not consist of many layers. This project demonstrates how something as simple as a 2D drawing can be transformed into a tangible 3D object through CAD software, giving it a practical application for students while encouraging them to be creative. This project would act as an introduction to 3D printing for schools who have not had experience with the technology before, providing them with foundational learning for future projects.

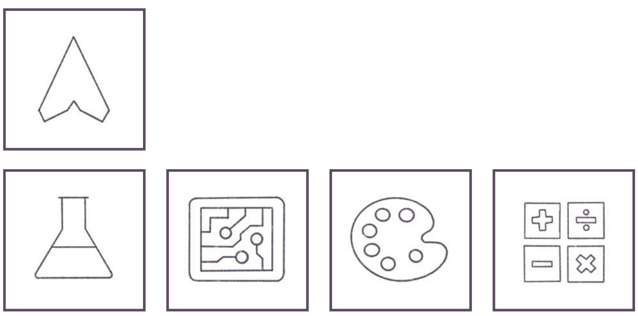


Figure 50: Cookie cutter collection

Figure 51: Making cookies

Figure 52: Bird's eye view of cookie cutters

SPINNING TOPS

Again, using students' drawings as initial inspiration, the second project 'Spinning Tops' is designed to build upon the foundational learning of 'Cookie Cutters'. For this project, students would be given a brief to design and 3D print modular spinning tops. This would involve the design of separate components which are combined to make a complete spinning top. The modular aspect allows for students to trial various configurations changing the different parts of spinning tops in combination with each other, to see which is the most successful. Students could work in groups, modifying and customising their designs working towards getting the fastest or longest spin from their spinning top. This project has the potential to be integrated into STEAM learning, being particularly suitable for the area of science, as the spinning tops could be used as a learning tool for physics. Students could explore momentum and forces through the customisation of different 3D printed forms. The spinning tops have also been designed to consider the ease of 3D printability. Printing the spinning tops as sections makes for shorter printing times as the parts are smaller and consist of less layers. Students would theoretically be able to produce their own modular spinning top within half an hour. Separating the spinning tops into sections allows for the print to build upon a solid base with the flat, larger side acting as the foundation for the print. This allows for easier 3D printing and more successful prints as there is no need for foundational support. This project demonstrates how 3D printing could be integrated into STEAM learning through students designing simple, customisable objects which can be configured in multiple ways to explore areas of physics such as momentum and forces.

Figure 53: Spinning top parts

Figure 54: Spinning top configurations

Figure 55: Spinning tops

PLANTERS

The third project, 'Planters', involves students working as teams to design a planter that is able to house a seedling plant for each student. Students would collectively research what kind of plant they want to grow, and decide upon the most suitable type of planter to create. Planters are an object that could be created in a variety of forms, ranging from basic shapes to complex character designs. Simple projects could consist of students making simple shelled shapes which they could use to hatch seedlings. More advanced challenges could involve students designing modular planters, with Figure 58 demonstrating how simple printed components can connect planters together. Modular planters could be integrated in the development of a school garden project. In this project, classes could connect their planters and construct a larger form which holds a seedling plant from each class member. CAD models for different planters could be downloaded from websites such as Thingiverse, which would save time on designing the form while still providing tangible examples of 3D printed upcycling. As planters are generally hollow, they can be printed in a relatively short amount of time and should not generally take longer than an hour. This project could also be integrated into the STEAM subject area of science, and the planters could be used as a learning tool for the areas of biology or sustainable education. The planters could be used to teach students about responsibility and how to grow a healthy plant. They would also have the potential to continue being reused into the future, providing a more sustainable alternative to the single-use plastic which is commonly used for housing plants kinds of projects.

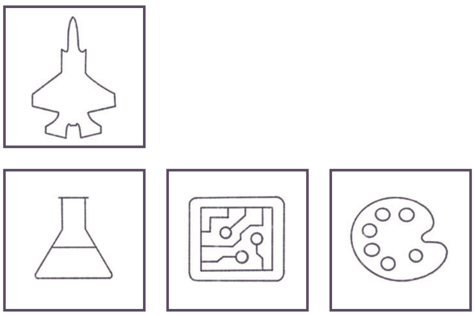


Figure 56: Bird's eye view of planters

Figure 57: Modular planter 01

Figure 58: Modular planter 02

Figure 59: Legged planter and Bulbasaur planter

Legged Planter by p4zR is licensed under the Creative Commons - Attribution - Non-Commercial - No Derivatives license. https://www.thingiverse.com/thing:2677108

Low Poly Bulbasaur by Hitsman is licensed under the Creative Commons - Attribution - Non-Commercial license. https://www.thingiverse.com/thing:381599

Figure 60: Planters

THE PARTICIPATION

Schools and students would be awarded for participating in this programme through being sent a CAD model for a prize which they could then print using their filament. This prize would be in the form of a modular object, with schools being able to build upon their prize every time they send plastic waste to the programme for processing into filament. Beginning as a singular level, an overall prize for the school would eventually assemble into a full object which could be displayed within the school, giving students a tangible way of seeing their schools' contribution towards the programme. As well as a prize for the school, students could be rewarded individually through tokens which would reward them for different achievements and contributions towards the programme. Teachers would be given CAD models for various reward tokens they could print for the students using their schools' upcycled filament, such as 'top contributor' and 'fastest spinning top'.

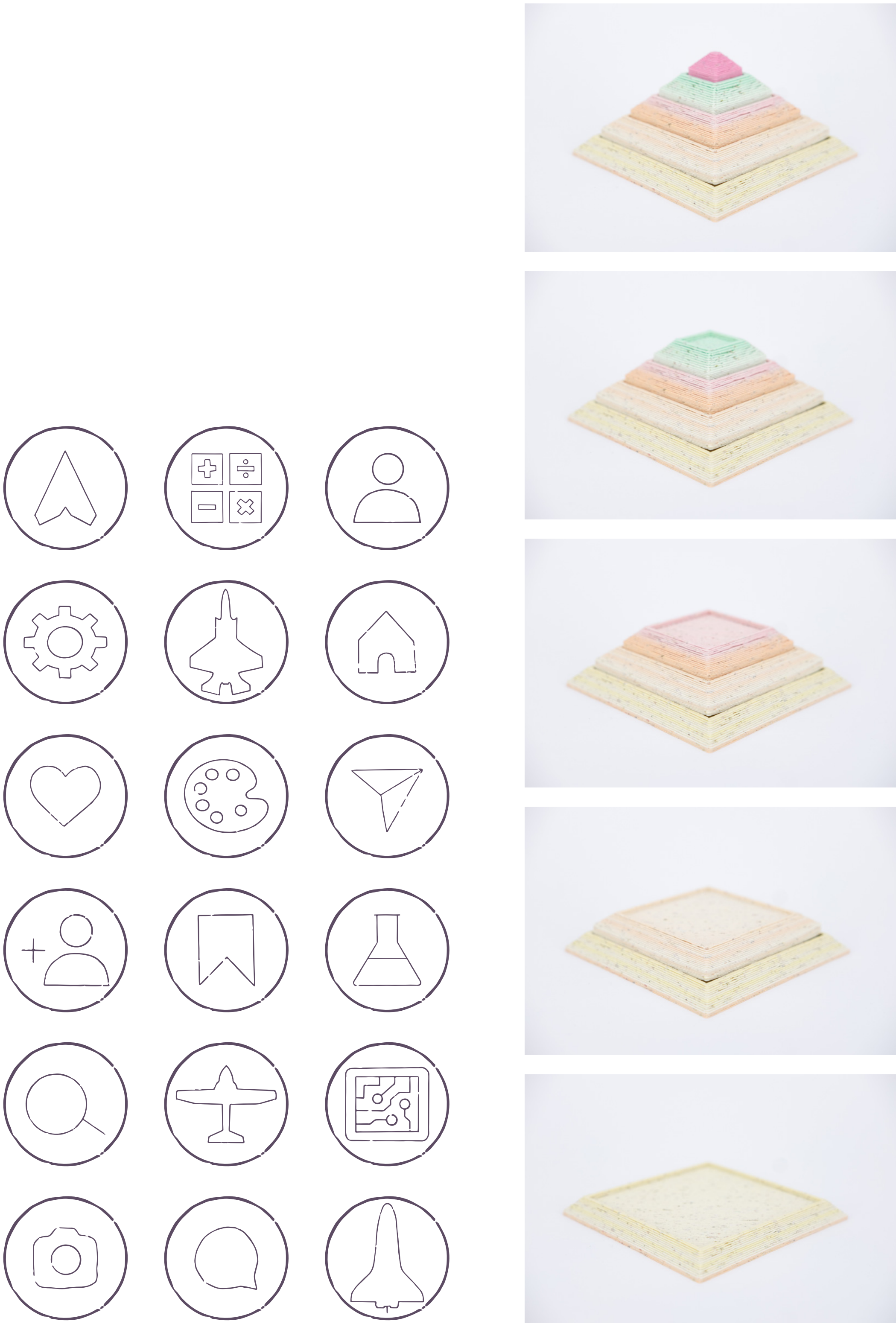


Figure 61: Token graphics and 3D printed pyramid participation

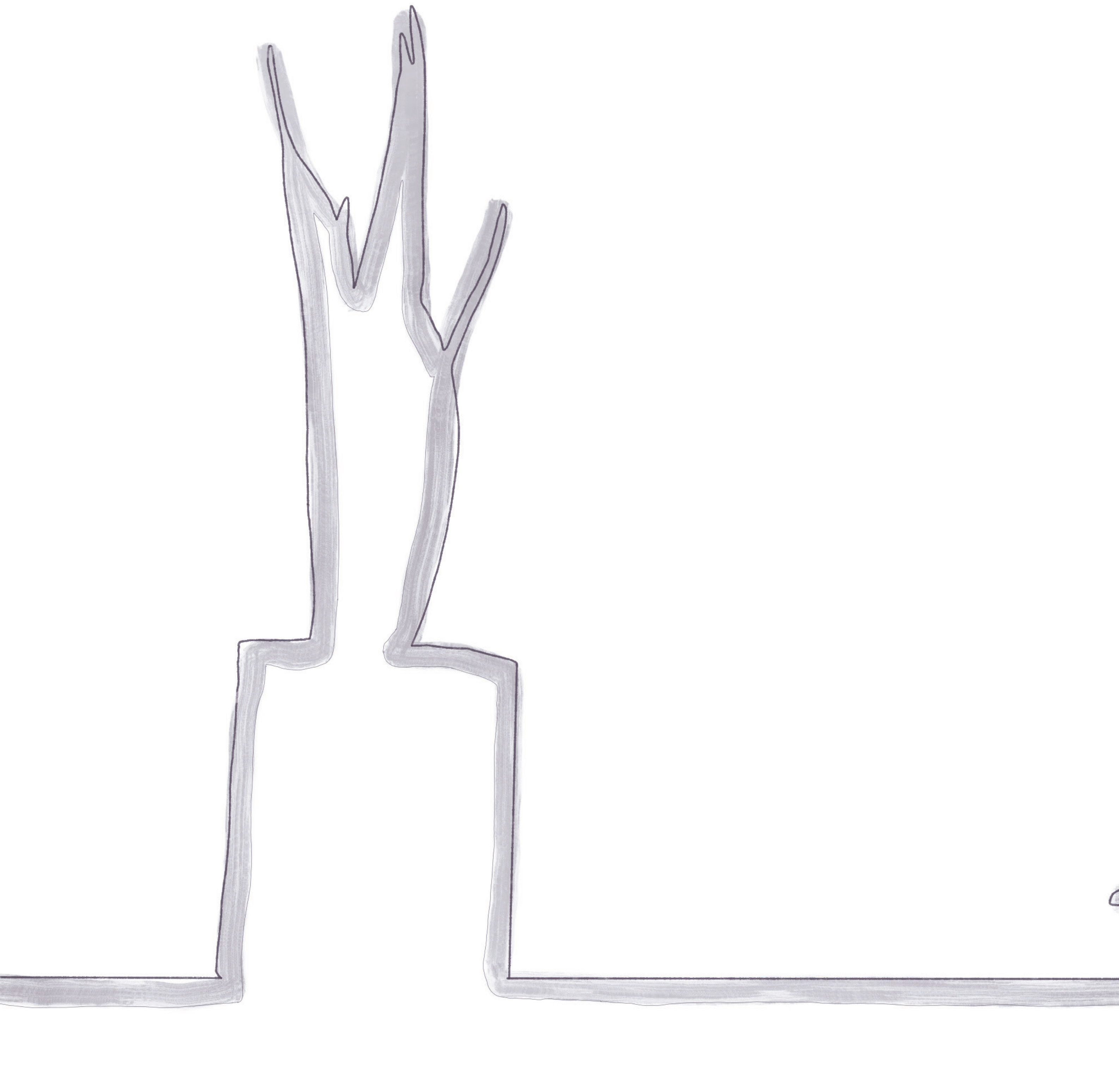
SUMMARY

These projects have been developed on the basis of what is achievable, easily printable and engaging for students. Using simple shapes that can be easily printed within the introductory project, 'Cookies Cutters' lays a basic foundation for students to understand how 3D printing works. Objects that would be printed by students in these projects have been tested to ensure they can be printed efficiently to ensure students each get the required time to have their own design printed. This can help prevent dissatisfaction with the programme for some students, as results from the questionnaire with School 03 indicated that students who hadn't been able to print their own design were less likely to associate the process as a positive experience.

Each of the projects supports students working as a group or individually, which was indicated to be an effective way of engaging students. They also support collaboration between individuals, groups and schools, encouraging students and teachers to share their knowledge and expand on the projects/programme through online platforms.

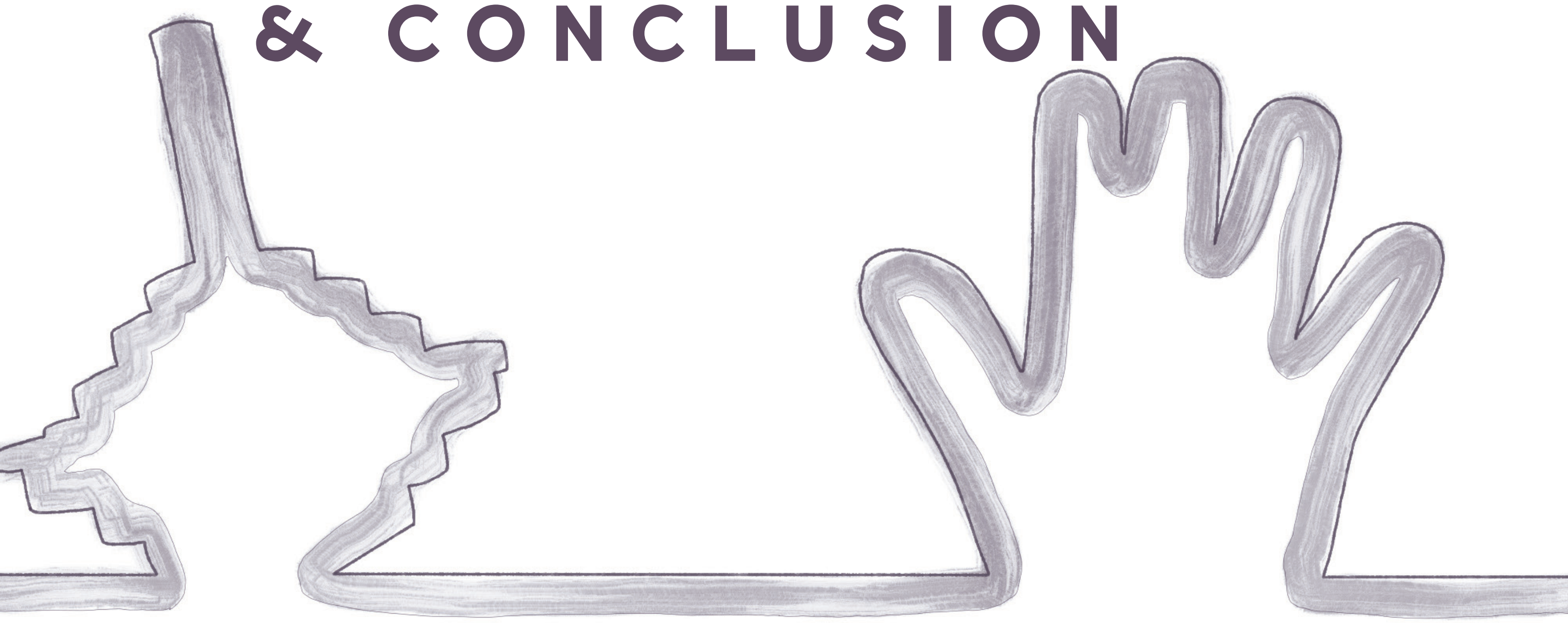
'Plastic in Practice' encourages participating schools to take charge of their own plastic waste stream and collection points, educating and encouraging students to take initiative and responsibility in sustainable systems in practice. Through providing tangible engagement, this programme gives students an immersive way to explore and investigate upcycling and 3D printing. Being able to print physical models allows students to test their design concepts to learn and see how things work, and help them recognise and consider what improvements can be made to develop the most successful outcome.

This programme has been designed to be suitable for integration with STEAM learning topics, with projects focusing on students creating educational tools which can be used for future learning, while teaching them about 3D printing and upcycling through the making process.



07

DISCUSSION & CONCLUSION



7.1

DISCUSSION

This research has informed an understanding of how an upcycled 3D printing education programme could be integrated into the framework of schools around New Zealand. The potential of using single-use dairy plastic as a filament for 3D printing has been evaluated through experiments with a variety of different plastic types including HDPE, HIPS and PE. HIPS was proven to be the most successful for 3D printing applications, which is extremely positive due to the fact that this type of plastic cannot easily be recycled in New Zealand.

Participatory research findings with both partner schools and teachers informed the criteria for the proposed education programme focused on 3D printed upcycling in New Zealand schools. The education programme expands upon ideas explored in the background research, utilising students' creative skills to re-conceptualise new systems, which is an essential step in shifting towards a circular economy. Using these ideas as an outline, this proposed programme could be further developed, and put into practice within schools around New Zealand. A range of projects have been developed which are both adaptable to a range of experience levels, and encourage student learning through tangible engagement. The proposed system aims to engage students with sustainable systems in practice, using 3D printed upcycling technologies as a learning tool.

IMPACT

This research has the potential to make an impact on the way sustainable topics are taught in schools around New Zealand, applying the tangible, empirical learning opportunities provided by technologies such as 3D printing. The project outlines act as exemplars for how the project would function within the classroom environment, and how 3D printed upcycling topics could be integrated within the curriculum. Projects have been developed on the basis of what 3D objects are simple, efficient and easy to print. This programme has the potential to create circular plastic upcycling systems within local communities and spread awareness of the impact of plastic waste on a national level. As well as this, it educates future generations about sustainable topics and engages them with innovative solutions to plastic waste.

HIPS, which is used to make yoghurt containers, was found to be the most successful filament for 3D printing. This gives the programme the potential to transform recycling around New Zealand as this type of plastic cannot be easily recycled within the country. Using HIPS as a material for students to create educational tools would help eliminate a large amount of this plastic going into landfill. However, due to the process of removing paper labels from HIPS packaging being quite difficult, there would have to be changes made to the way this packaging is constructed to make elements more easily removable. This would allow students to separate elements of HIPS plastic for processing into filament. Other non-recyclable packaging, which often consists of a mixture of material, was found to be relatively successful and could be upcycled within the programme with some further refinement.

LIMITATIONS

As an entire education programme involves multiple steps and would be very complex, it would need the assistance and approval from a range of parties (schools, government, etc.) in order to be fully developed and implemented. There would have to be more consideration into the logistics of the programme, particularly how the plastic waste would be processed into filament. This could be done at a plastic manufacturing facility, but would ideally be organised by a partner company for the programme such as Fonterra. Although participatory research findings helped form an understanding of the school environment, the research might still be somewhat limited due to being developed from a designer's perspective, rather than an educators'.

FUTURE RESEARCH

Input from both students and teachers was immensely helpful in the development of both the overall programme and lessons, and further collaboration with schools would be essential in order to put this programme into practice. The three project outlines would ideally be tested in the school environment, to see which projects are the most successful, and how they could potentially be developed to get the most engagement from students. Testing of the projects would also allow teachers to give a more informed input of how the programme could be improved, as they would have first-hand experience in teaching the programme. As well as this, it would be important to determine how well these projects align with the current curriculum and whether these projects could be modified to further fit into STEAM learning. Currently, the projects mainly focus on the area of science, future projects could expand and build upon this to suit a wider range of subjects such as engineering, maths and arts.

Further research would also be needed to refine the filament making process to ensure that schools could be sent back a reliable filament for 3D printing. In this research, an extremely successful filament for 3D printing was developed through using HIPS. However, results from the HDPE and PE plastic were less successful due to warping and shrinkage and further research into how to efficiently use these other plastic types would be extremely beneficial to the adaptability of this programme.

7.2

CONCLUSION

This research has uncovered new ways to engage students with sustainable systems in practice through the empirical, tactile learning opportunities provided by 3D printing technology.

It was found that there is huge potential for using HIPS plastic for 3D printed upcycling within New Zealand schools. As this type of plastic is not currently recyclable in New Zealand, this could make a huge impact on reducing the amount of plastic waste being sent to landfill.

An informed understanding of how 3D printed upcycling could fit within the curriculum has been developed through collaborating with schools around New Zealand. The programme proposal outlines the key elements which would need to be integrated within the programme, with the example projects demonstrating how 3D printed upcycling could be integrated within STEAM subjects currently taught within the curriculum. Furthermore, this research demonstrates how more tangible learning methods such as the 3D printing of learning tools with a practical application can engage students with innovative solutions to plastic waste. 'Plastic in Practice' has the potential to create localised upcycling systems within schools around the country, engaging students with sustainable systems in practice, and inspiring a cultural shift towards a more circular economy.

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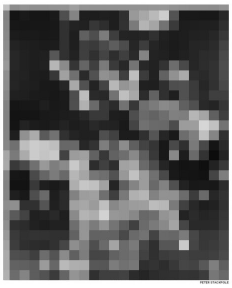
8.1

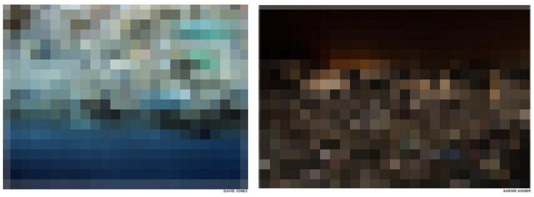
APPENDIX A

PLASTIC WASTE UPCYCLING
IN NEW ZEALAND SCHOOLS

MADDISON JESSOP-BENSEMAN



WE LOVE...

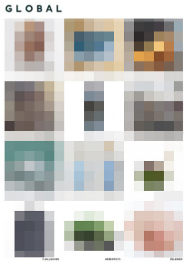


...TO HATE...

...PLASTIC

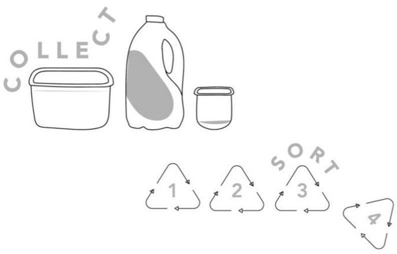
UPCYCLING

GLOBAL

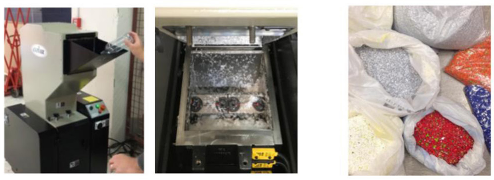


LOCAL

STEP 1 - SORTING & CLEANING

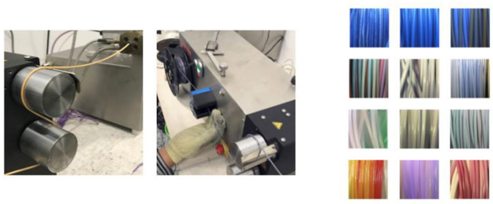


STEP 2 - GRINDING & GRANULATING

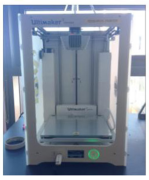


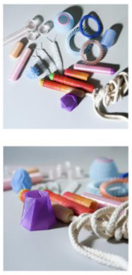
STEP 3 - MELTING & EXTRUDING

STEP 4 - COOLING & SPOOLING

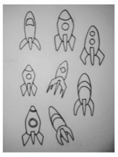


STEP 5 - 3D PRINTING

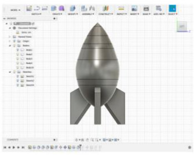




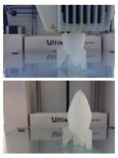
3D PRINTING - PROCESS



Iteration



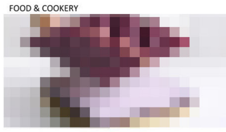
3D Modelling



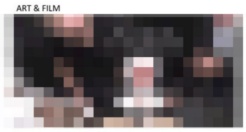
3D Printing

3D PRINTING - APPLICATIONS

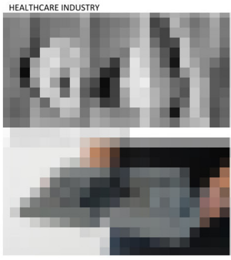
FOOD & COOKERY



ART & FILM



HEALTHCARE INDUSTRY

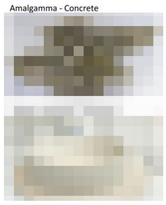


PRODUCT DESIGN, PROTOTYPING & MANUFACTURING

3D PRINTING - MATERIALS

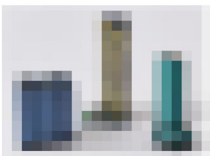
Hot Pop Factory - Plastic

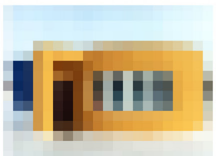
Amalgamma - Concrete

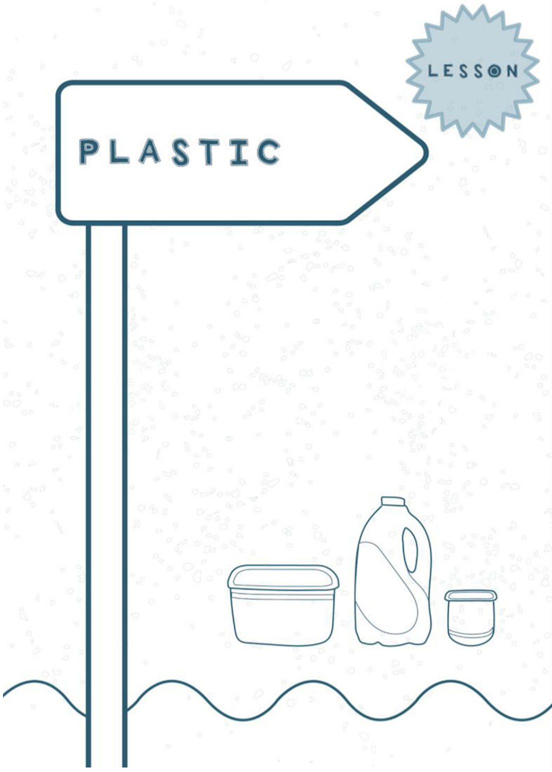


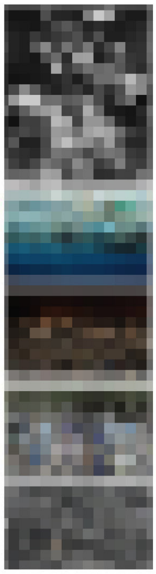
MIT - Glass

3D PRINTING - SMALL SCALE & LARGE SCALE









WE LOVE ...

Plastic has become a really important and widely used material in our society.

Plastic products can be made and produced at a very low cost, making it a convenient material to use for manufacturing new products.

We use plastic for a lot of things, from building and construction to packaging and toys.

... TO HATE ...

Despite the benefits of using plastic, plastic's entire lifecycle has negative effects on our planet.

Most types of plastics are not biodegradable, and are instead extremely durable.

This means that most plastics that are manufactured today could be contaminating our environments for decades, even centuries.

... PLASTIC

In New Zealand, we struggle to deal with our plastic waste.

A large majority of our waste is being buried in landfills or simply dumped and left to contaminate the environment.

Plastic waste is polluting our animals and environments; waterways and oceans; and even our food and bodies.

PLASTIC IDENTIFICATION CODES

1	PET Polyethylene Terephthalate	Soft drink and water bottles, food packaging such as salad, fruit and biscuit trays.
2	HDPE High Density Polyethylene	Milk bottles, ice cream containers, shopping bags, detergent and shampoo bottles.
3	PVC Polyvinyl Chloride	Cosmetic containers, pipes, films, wire coatings, and garden hoses.
4	LDPE Low Density Polyethylene	Most soft plastics, squeezable bottles, rubbish bags and plastic food wrap.
5	PP Polypropylene	Lunch boxes, microwave containers, straws, packaging film and dairy food containers.
6	PS Polystyrene	Plastic cutlery, toy parts, packaging for fragile goods, food take-away containers and cups.
7	OTHER Polycarbonate, Polylactic, Nylon etc.	Car parts, appliance parts, electronics, biodegradable plastics and other packaging.

Recycled ...
Commonly
Sometimes
Almost Never

HOW TO IDENTIFY DIFFERENT TYPES OF PLASTIC

Anchor Cream

Bottle -
HDPE - High Density Polyethylene 2

Lid -
HDPE - High Density Polyethylene 2

Philadelphia
Caramilk Cream Cheese

Main container -
PP - Polypropylene 5

Lid -
PP - Polypropylene 5

There are several different types of plastic.

Each type of plastic has its own unique properties and uses.

Some types of plastic are hard and rigid while others are more soft and flexible.

Most plastics should have their identification code somewhere on the plastic itself. It is usually labeled on the bottom or sides of products.

In New Zealand we are able to recycle some plastics but not others.

When you are recycling plastics it is important to wash any food contaminates, otherwise it is likely your plastic will just be sent to landfill.


LESSON
UPCYCLING
Up-cycling is the process of taking old or discarded materials. The materials are then made into creative objects that will be used for a longer time.
This can help prevent the plastics from entering the landfill, or oceans.
It also helps create awareness among consumers when it comes to purchasing new products.
Plastic waste is a really great material to up-cycle as it can be reprocessed several times before degrading in quality.
UPCYCLED PRODUCT EXAMPLES
ecoBirdy in Belgium created a system where old, unused toys are collected and upcycled into kids furniture pieces.
Adidas x Parley teamed up to design and produce a range of sneakers made from old, discarded fishing nets.
Precious Plastics is an open source global project. This bench has been made with a mix of HDPE and PP using their own machinery.
The New Raw digitally crafted these seashell sculptures and 3D printed them using upcycled marine plastic.
For more information click the dot next to the images.


THE PROCESS
OF UPCYCLING PLASTIC WASTE
INTO 3D PRINTING FILAMENT
COLLECT + CLEAN
- The first step is to collect a decent amount of plastic waste.
- One of the most important things is to make sure your plastics are cleaned thoroughly.
- This will prevent any left over food contaminates from making the plastics mouldy and smelly.
- During this stage all stickers on plastics need to be removed.
2
SORTING
- Plastics can then be sorted into their individual types.
- Once the plastics are sorted by type, they can then be grouped by colour. This is so different coloured filaments can be made.
GRINDING + GRANULATING
- The plastic is then put through a machine that shreds it into small pieces, known as granules.
MELTING + MOULDING
- The granulated plastic can then be measured out and placed in an extruder.
- Plastic gets slowly pushed along heated metal rods which slowly melt the plastic.
- Once the plastic has melted it flows out at the end in a gloopy looking strand.
COOLING + SPOOLING
- The plastic strand is still very hot at this point so it needs to cool down.
- The strand of plastic rolls across cool metal bars which also stretches and thins it out a bit.
- This is to control the diameter of the filament which is important for 3D printing.
3D PRINTING
- Once the spool of filament is made it can be used for 3D printing.
- Time to create a design and begin 3D printing using the up-cycled plastic filament.

LESSON

3D PRINTING

3D printing is a technology that lets you create objects from your computer.

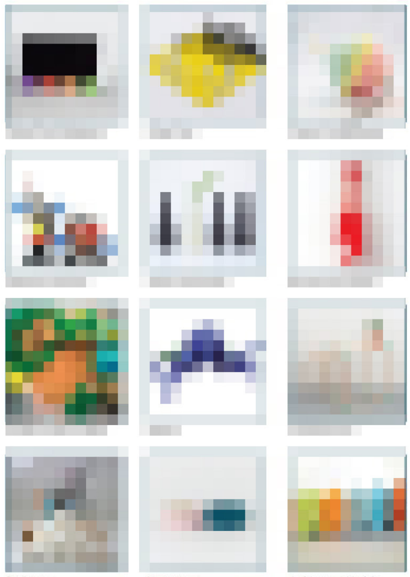
Objects are created by adding layers of material to vertically form a 3D object.

There are many different materials that can be used for 3D printing.

This includes materials like wood filaments, metals, ceramics, food and many more.

Printing a 3D object can take hours or days to complete, depending on the complexity and size of the object.

3D PRINTING - APPLICATIONS



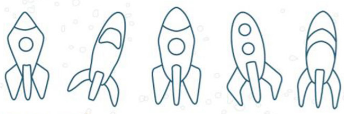
Stationary

Homewares

Architecture Models

+ way more other possibilites and things to 3D print!

3D PRINTING - PROCESS

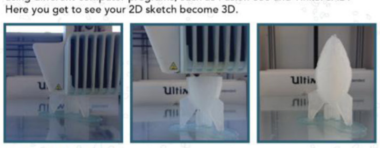


ITERATE

Drawing out your idea is the first step. Iterating is when heaps of designs are sketched out to help determine the best looking outcome for what you have in mind.

3D MODEL

Once the final design is chosen it can be 3D modeled. This can be done using different computer programs, such as Fusion 360 and TinkerCAD. Here you get to see your 2D sketch become 3D.



3D PRINT

The final step is to 3D print your design. Load up your filament materials and use a slicer program to send your 3D model to the 3D printer. Then watch as your design becomes truly 3D.

DRAW

ACTIVITY

Now that you have seen some examples of 3D printing hopefully it has inspired you to think about what you might want to make using a 3D printer.

For this activity, have a think about something you would want to 3D print using up-cycled plastic. Draw your idea out on a piece of paper. Make sure you give your drawing a name and note any important features.

You could draw something that could be used at school, in the classroom, at home or anything else you can think of. Think about who you might want to 3D print something for. It could be for yourself or you might want to gift your creation to your friends and family.

Most 3D printed objects are limited in size. For your idea you can pick ONE of these sizes.

$10cm^3$ $30cm^3$ $100cm^3$

And finally, once you have completed your drawing take a clear photo and upload it to the Google Classroom.

COLLECT

ACTIVITY

For the next couple of weeks start to make a collection of plastic bottle caps from dairy products.

These could be from milk bottles, cream bottles or any other dairy product you might use at home.

You can also collect the little rings that are around the top of the bottle if you wish.

You can collect any brand and any colour.

The most important thing about your collection is that you wash them well.

You can do this by washing them in the sink with hot soapy water, they can then be left to air dry.

Once they are completely dry you can put the bottle caps in a airtight container or snap-lock bag.

If we manage to collect enough bottle caps, we could potentially turn them into a filament for 3D printing.

Good luck with your collection! How many do you think you can collect?

DAIRY DIARY

ACTIVITY

Over the next 2 weeks start to take note of what your family is recycling and throwing away.

For this diary focus specifically on dairy product packaging.

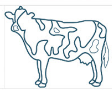
Dairy products are any food items that are milk based, this could be anything from milk bottles to yoghurt pouches to a bag of grated cheese.

Take note of:

- What the product is, identifying the brand and food product.
- The size of the product, most items should have the weight/measurement amount on the packet.
- The colour of the plastic, this might be just one colour or a couple of colours. Don't worry about including stickers.
- Finally, try to identify what type of plastic it is, this could be on the labeling or imprinted some where on the plastic itself. See if you can find it.

You can use the Google sheets document in the folder to fill out your entries.

DAIRY DIARY



ACTIVITY

WEEK ONE

	PRODUCT	SIZE	COLOUR	TYPE	TALLY
EXAMPLE	Anchor milk bottle	2L	White + Blue	2 - HDPE	III
EXAMPLE	Philadelphia cream cheese	250g	White + Silver	5 - PP	II

WEEK TWO

PRODUCT	SIZE	COLOUR	TYPE	TALLY

3D Printing

Have you done any 3D printing?

- ◯ YES
- ◯ NO

If yes, what did you print? If no, what would you want to print?

Your answer

Do you like the idea of 3D printing?

- ◯ YES
- ◯ NO
- ◯ MAYBE

Why?

Your answer

How difficult would you rate 3D printing?

	1	2	3	4	5	
EASY	◯	◯	◯	◯	◯	HARD

List anything you can think of that is good about 3D printing?

Your answer

List anything you can think of that is not so good about 3D printing?

Your answer

What is the most interesting thing you've seen that is 3D printed?

Your answer

Submit

Teacher Survey

Thank you for taking time to participate in this survey. There are five sections with four questions in each. You are not required to answer every question and there are no right or wrong answers.

What is your job title?

Your answer

What do you enjoy most about your job?

Your answer

What school level do you teach?

- ◯ Primary
- ◯ Intermediate
- ◯ Secondary
- ◯ Other: __________

What are some specific subjects you have experience in teaching?

Your answer

School Waste Management, Practices and Policy

If any, please list some current practices in place at the school regarding waste management. ie. Paper recycling, compost collection etc.

Your answer

What is the teaching staff's involvement with these practices?

Your answer

What is the school's current policy on managing plastic waste?

Your answer

What would you ideally like to happen within the school regarding plastic waste?

Your answer

Sustainability and Waste Management within the Curriculum

If any, please list some past or current learning or practices in place at the school regarding sustainability and waste management. ie. Recycling awareness, worm farms, alternative energy etc.

Your answer

What sorts of tools or resources do you utilise to educate your students about sustainability and waste management? ie. Online resources, posters, workshops etc.

Your answer

How have the students responded and engaged with this learning?

	1	2	3	4	5	6	7	8	9	10	
Completely disinterested	○	○	○	○	○	○	○	○	○	○	They love it! Want to learn more

How confident are you in your personal knowledge about the concept 'reduce, reuse, recycle' and your ability to teach this concept?

	1	2	3	4	5	6	7	8	9	10	
Not at all confident	○	○	○	○	○	○	○	○	○	○	Very confident

3D Printing within the Curriculum

What sorts of tools or resources does your school currently utilise to educate students about physical crafting methods? ie. workshops, 3D printing, sculpture etc.

Your answer

If any, please list any subjects that you believe could benefit from using 3D printing as a learning and making tool.

Your answer

If you can think of any, please list some potential projects or objects you could imagine students creating using 3D printing?

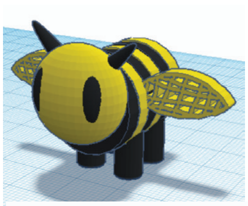
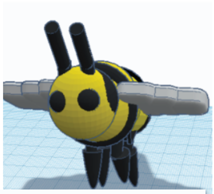
Your answer

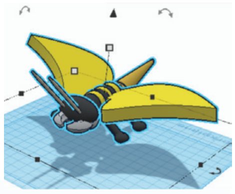
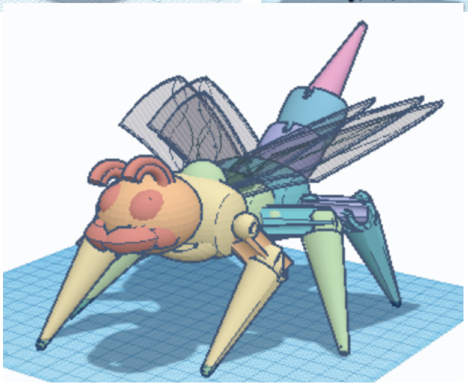
How confident are you in your personal knowledge about 3D printing and your ability to teach 3D printing in the classroom?

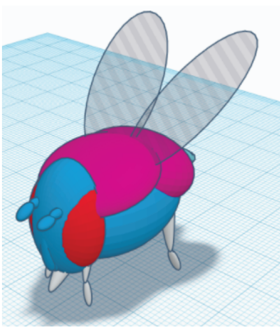
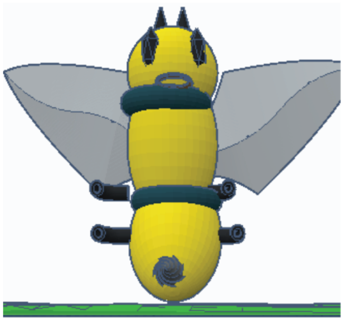
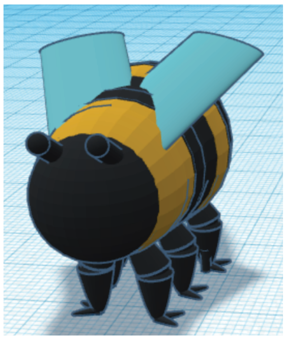
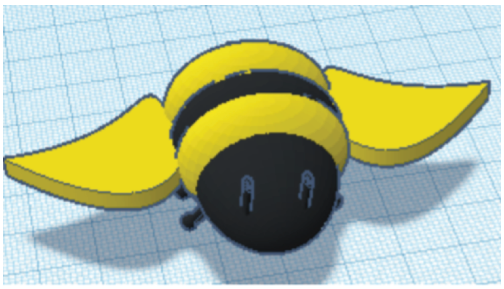
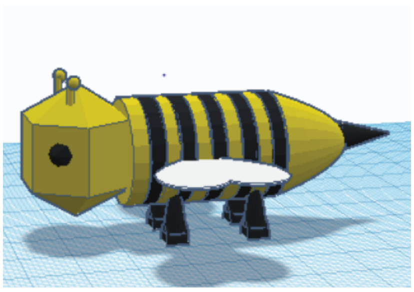
	1	2	3	4	5	6	7	8	9	10	
Not at all confident	○	○	○	○	○	○	○	○	○	○	Very confident

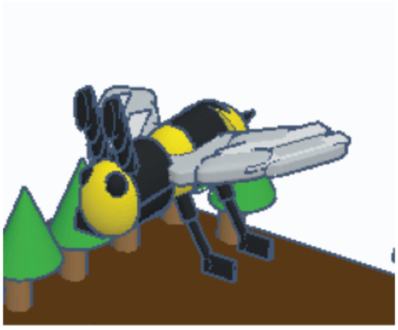
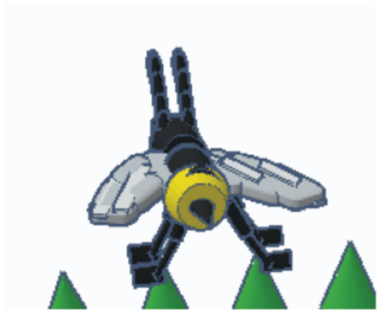
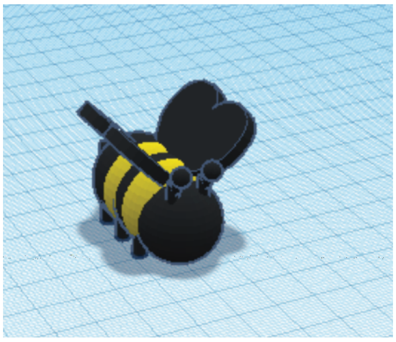
Thank you for completing this survey. I would greatly appreciate any further comments, thoughts or questions you might have about this research.

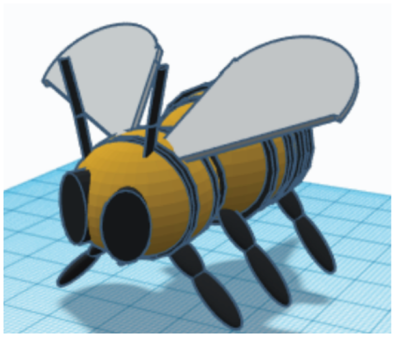
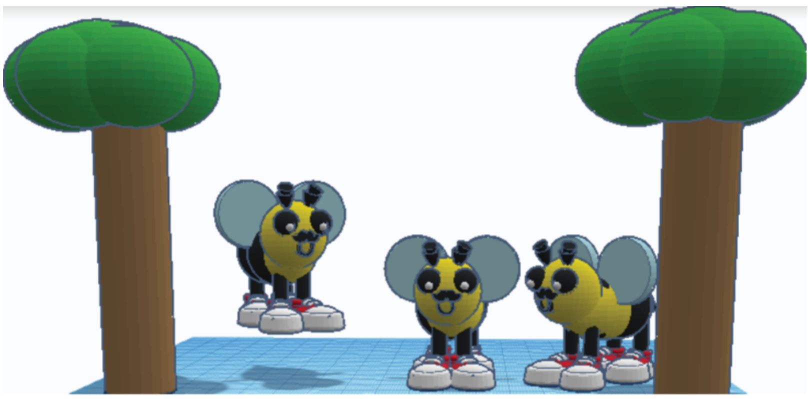
Your answer

9.1

APPENDIX B

Opt Out Form for Parents/Guardians

TE HERENGA WAKA
WELLINGTON
VICTORIA UNIVERSITY OF WELLINGTON

Plastic Waste Up-cycling in New Zealand Schools

OPT OUT FORM FOR PARENTS/GUARDIANS

Thank you for reading the information sheet about my research Plastic Waste Up-cycling in New Zealand Schools. Please make contact if there is anything that is not clear or if you would like more information.

If you do NOT wish for your child to take part then please fill in the details below and return to your child's school.

☐ NO, I do NOT wish for my child to take part in the study.

Name of child

Your answer

Name of Parent or Guardian

Your answer

Date

Date

dd/mm/yyyy

IF YOU HAVE ANY QUESTIONS OR PROBLEMS, WHO CAN YOU CONTACT?

If you have any questions, either now or in the future, please feel free to contact either:

Submit

TE HERENGA WAKA
WELLINGTON
VICTORIA UNIVERSITY OF WELLINGTON

Plastic Waste Up-cycling in New Zealand Schools

INFORMATION SHEET FOR PARENTS/GUARDIANS

Your child has been invited to take part in this research. Please read this information before deciding whether or not you give permission for your child to take part. If you decide your child will participate, thank you. If you decide your child will not participate please fill out the 'opt out' form, and thank you for considering this request.

WHO AM I?

My name is Maddison Jessop-Benseman, and I am a Masters of Design Innovation student at Victoria University of Wellington.

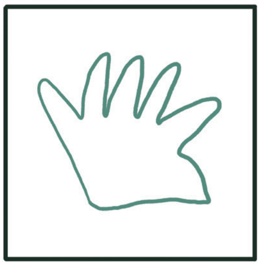
I am working on research towards my Masters research portfolio.

In March I visited your child's class to present and discuss my research about plastic waste, upcycling and 3D printing. During the presentation students completed some activities. One of these activities was a drawing. For the drawing I asked students to "Imagine your own 3D printed object..."

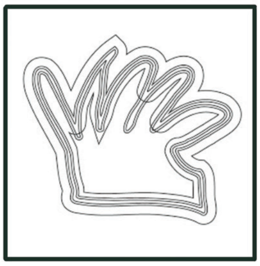
HOW YOU CAN HELP

Using the drawings I have created some 3D models to be used as cookie cutters. I have been using these models to test my 3D printing filament made from dairy plastic waste.

To republish students drawings as part of my final Masters research portfolio I need both your and your child's permissions. I would like to present everyone's drawings as a collection and use some of them to design cookie cutters for 3D printing. In my thesis it will look something like this:



Student's drawing



3D model

3D print

WHAT WILL HAPPEN TO THE INFORMATION YOUR CHILD GIVES?

The information from this research will be used in my Masters research portfolio. There is also potential for this research to be used within the context of academic or professional conferences, exhibitions and journals.

This research is confidential. This means if your child agrees to me using their drawing, their name will not be used in any reports, presentations or public documentation.

TE HERENGA WAKA
WELLINGTON
VICTORIA UNIVERSITY OF WELLINGTON

Plastic Waste Up-cycling in New Zealand Schools

INFORMATION SHEET FOR STUDENTS

You have been invited to take part in this research. Please read this information before deciding whether or not you would like to take part. If you decide you will participate, thank you. If you decide not to participate, thank you for considering this request.

WHO AM I?

My name is Maddison Jessop-Benseman, and I am a Masters of Design Innovation student at Victoria University of Wellington.

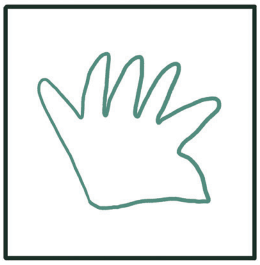
I am working on research towards my Masters research portfolio.

Back in March I visited your class to present and discuss my research about plastic waste, upcycling and 3D printing. You may remember I got you to complete some activities. One of these activities was a drawing. For the drawing I asked you to "Imagine your own 3D printed object..."

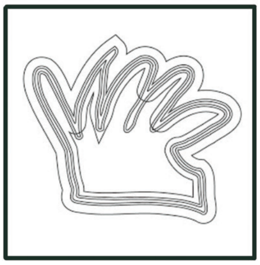
HOW YOU CAN HELP

Using the drawings I have created some 3D models to be used as cookie cutters. I have been using these models to test my 3D printing filament made from dairy plastic waste.

To republish your drawings as part of my final Masters research portfolio I need your permission. I would like to present everyone's drawings as a collection and use some of them to design cookie cutters for 3D printing. In my thesis it will look something like this:



Your drawing



3D model

3D print

WHAT WILL HAPPEN TO THE INFORMATION YOU GIVE?

This research is confidential. This means if you agree to me using your drawing, your name will not be used in any reports, presentations or public documentation. It could also be shown at conferences, exhibitions or in journals. If you decide not to give permission, that's ok, and your teacher and I won't mind. If you do decide to give permission please recognise your work and fill out the assent form.

TE HERENGA WAKA
WELLINGTON
VICTORIA UNIVERSITY OF WELLINGTON

Plastic Waste Up-cycling in New Zealand Schools

ASSENT FORM FOR STUDENTS

Thank you for reading the information sheet about my research Plastic Waste Up-cycling in New Zealand Schools. Please talk to your teacher if there is anything that is not clear or if you would like more information.

If this is your work and you wish to take part then please fill in the details below and give this form back to your teacher.

☐ YES, I would like to take part in this research

☐ YES, I understand that some of my work could be republished in a Masters Research Portfolio

☐ YES, I understand my name will not be used in reports and utmost care will be taken not to disclose any information that would identify me

☐ YES, I have talked about this research with my parent/s or guardian/s

☐ YES, my parent or guardian has read the information sheet

Your name

____

Name of Parent or Guardian

____

Date

____

TE HERENGA WAKA
WELLINGTON
VICTORIA UNIVERSITY OF WELLINGTON

Plastic Waste Up-cycling in New Zealand Schools

INFORMATION SHEET FOR PARENTS/GUARDIANS

Your child has been invited to take part in this research. Please read this information before deciding whether or not you give permission for your child to take part. If you decide your child will participate, thank you. If you decide your child will not participate please fill out the 'opt out' form, and thank you for considering this request.

WHO AM I?

My name is Maddison Jessop-Benseman and I am a Masters student in Design Innovation at Victoria University of Wellington. This project is work towards my Masters Research Thesis.

WHAT IS THE AIM OF THIS RESEARCH?

This project aims to explore whether there is an opportunity in the future to involve New Zealand schools in a 3D printing up-cycling program, educating and engaging New Zealand school children about the capabilities of plastic waste up-cycling. Your child's participation will support this research by providing data about: the motivation and ability students have to collect and clean plastic waste; how much plastic waste can be collected by students; what ideas they may have for 3D printed outputs; and insight into students thoughts and experiences with 3D printing. This research has been approved by the Victoria University of Wellington Human Ethics Committee 0000027808.

HOW CAN YOU HELP?

St Bernard's College has been invited to participate as they have previous experience with 3D printing and have expressed an interest in participating in this research. If you agree to take part your child will be set a selection of 4 simple activities to complete over a 2-week period. These activities include:

'Collect' - an activity that asks students to collect and clean bottle caps from dairy products. I hope to use these bottle caps to process into 3D printing filament and in turn create 3D prints to give back to the students.

'Dairy Diary' - encourages students to record what plastic dairy packaging is being used and thrown away in your household. Students will note down: what the plastic item is; the size; the colour; and the type of plastic. The results from these diaries will be aggregated, analysed and represented graphically as part of my thesis.

'Draw' - asks students to think of something they would like to 3D print and create a simple drawing of their idea. The students drawings will be collated and displayed in a grid format and republished as part of my research thesis.

And finally a short **'questionnaire'** containing 8 questions will be given to students. The purpose of this questionnaire is to gain some insight into students' experiences and thoughts about 3D printing specifically. Data will be aggregated, analysed and represented graphically as part of my thesis.

WHAT WILL HAPPEN TO THE INFORMATION YOUR CHILD GIVES?

This research is confidential. This means that the researcher named below will be aware of your child's identity but the research data will be combined and their identity will not be revealed in any reports, presentations, or public documentation.

Only my supervisors and I will review the raw data. All data, drawings and summaries will be kept securely and destroyed on 01/10/2021.

WHAT WILL THE RESEARCH PRODUCE?

The information from this research will be used in my Masters research portfolio. There is also potential for this research to be used within the context of academic or professional conferences, exhibitions and journals.

IF YOU ACCEPT THIS INVITATION, WHAT ARE YOUR RIGHTS?

You do not have to accept this invitation if you don't want to. If you do decide your child will participate, you have the right to:

- be opted out anytime before the final submission 03/07/2020;
- choose which of the activities they complete and submit;
- ask any questions about the study at any time.

IF YOU HAVE ANY QUESTIONS OR PROBLEMS, WHO CAN YOU CONTACT?

If you have any questions, either now or in the future, please feel free to contact either:

STUDENT:

SUPERVISOR:

Opt Out Form for Parents/Guardians

TE HERENGA WAKA
WELLINGTON
VICTORIA UNIVERSITY OF WELLINGTON

Plastic Waste Up-cycling in New Zealand Schools

OPT OUT FORM FOR PARENTS/GUARDIANS

Thank you for reading the information sheet about my research Plastic Waste Up-cycling in New Zealand Schools. Please make contact if there is anything that is not clear or if you would like more information.

If you do NOT wish for your child to take part then please fill in the details below and return to your child's school.

☐ NO, I do NOT wish for my child to take part in the study.

Name of child

Your answer

Name of Parent or Guardian

Your answer

Date

Date

dd/mm/yyyy

IF YOU HAVE ANY QUESTIONS OR PROBLEMS, WHO CAN YOU CONTACT?

If you have any questions, either now or in the future, please feel free to contact either:

Submit

TE HERENGA WAKA
WELLINGTON
VICTORIA UNIVERSITY OF WELLINGTON

Plastic Waste Up-cycling in New Zealand Schools

INFORMATION SHEET FOR STUDENTS

You have been invited to take part in this research. Please read this information before deciding whether or not you would like to take part. If you decide you will participate, thank you. If you decide not to participate, thank you for considering this request.

WHO AM I?

My name is Maddison Jessop-Benseman, and I am a Masters student.

I study Design Innovation at Victoria University of Wellington.

I am working on research towards my Masters research portfolio.

WHAT IS MY RESEARCH?

My research focuses on plastic waste, up-cycling and 3D printing.

Plastic is hard to recycle so a lot of it ends up in the landfill. It ends up polluting our oceans and waterways.

Up-cycling provides a way to create something from the plastic waste. You can create anything from toys to a piece of furniture. 3D printers can be used to create these objects.

I am exploring if there is an opportunity to involve New Zealand schools in a program that educates students about up-cycling and 3D printing. This research is aimed to educate and engage New Zealand school children about the capabilities of plastic waste up-cycling.

HOW YOU CAN HELP

You can help me in this project by completing some creative activities. These activities will focus on plastic waste, up-cycling and 3D printing. There are 4 different activities to think about and work on over the next 2 weeks, these are:

Collect - an activity that asks you to collect and properly clean plastic bottle caps from dairy packaging. If enough bottle caps are collected they could be made into filament used for 3D printing.

Dairy Diary - a dairy to record what plastic dairy packaging is being used and thrown away in your household. You will be asked to note down: what the plastic item is; the size; the colour; and the type of plastic.

Draw - this activity gives you the opportunity to think of anything you would like to 3D print and create a simple drawing of your idea.

Questionnaire - and finally a short questionnaire to find out a bit about your experiences and thoughts on 3D printing.

WHAT WILL HAPPEN TO THE INFORMATION YOU GIVE?

The information from this research will be used in my Masters research portfolio.
The information you provide in both the Dairy Diary activity and 3D printing questionnaire will be presented as graphs and published in my final Masters research portfolio.
I will also include all completed drawings as a combined collection to republish in my final Masters research portfolio. It could also be shown at conferences, exhibitions or in journals.

This research is confidential. This means if you participate, your name will not be used in any reports, presentations or public documentation. You can complete any or all of these activities just for class, or you can give me permission to use them as part of my project. If you decide not to give permission, that's ok, and your teacher and I won't mind. If you do decide to give permission please fill out and submit the online assent form.

IF YOU HAVE ANY QUESTIONS OR PROBLEMS, WHO CAN YOU CONTACT?

If you have any questions, either now or in the future, please feel free to contact either:

STUDENT:

SUPERVISOR:

Assent Form for Students

TE HERENGA WAKA
WELLINGTON
VICTORIA UNIVERSITY OF WELLINGTON

Plastic Waste Up-cycling in New Zealand Schools

ASSENT FORM FOR STUDENTS

Thank you for reading the information sheet about my research Plastic Waste Up-cycling in New Zealand Schools. Please talk to your teacher if there is anything that is not clear or if you would like more information.

If you wish to take part then please fill in the details below and submit this form.

☐ YES, I would like to take part in this research

☐ YES, I understand that some of the work I do for these activities could be republished in a Masters Research Thesis

☐ YES, I understand my name will not be used in reports and utmost care will be taken to not disclose any information that would identify me

☐ YES, I have talked about this research with my parent/s or guardian/s.

☐ YES, my parent or guardian has read the information sheet.

Your name

Your answer

Name of Parent or Guardian

Your answer

Date

Date

dd/mm/yyyy

IF YOU HAVE ANY QUESTIONS OR PROBLEMS, WHO CAN YOU CONTACT?

If you have any questions, either now or in the future, please feel free to contact either:

STUDENT:

Name: Maddison Jessop-Benseman

Email address: jessopmadd@myvuw.ac.nz

SUPERVISOR:

Name: Jeongbin Ok

Role: Supervisor

School: Victoria Univeristy of Wellington

Email address: jeongbinok@vuw.ac.nz

HUMAN ETHICS COMMITTEE INFORMATION

This research has been approved by the Victoria University of Wellington Human Ethics Committee 0000027808.
If you have any concerns about the ethical conduct of the research you may contact the Victoria University HEC Convenor: Dr Judith Loveridge. Email hec@vuw.ac.nz or telephone +64-4-463 6028.

Submit

TE HERENGA WAKA
WELLINGTON
VICTORIA UNIVERSITY OF WELLINGTON

Plastic Waste Up-cycling in New Zealand Schools

INFORMATION SHEET FOR TEACHERS

You are invited to take part in this research. Please read this information before deciding whether or not to take part. If you decide to participate, thank you. If you decide not to participate, thank you for considering this request.

WHO AM I?

My name is Maddison Jessop-Benseman and I am a Masters student in Design Innovation at Victoria University of Wellington. This project is work towards my Masters Research Thesis.

WHAT IS THE AIM OF THIS RESEARCH?

This project aims to explore whether there is an opportunity to involve New Zealand schools in a 3D printing upcycling program, that aims to educate and engage New Zealand school children about the capabilities of plastic waste upcycling and 3D printing technologies. To inform my research I am wanting to find out from both teachers and students their experiences, thoughts and desires about waste management, sustainability and 3D printing within a school context. Your participation will support this research by providing data about: school waste management, practices and policy; sustainability and waste management within the curriculum; and 3D printing within the curriculum.
This research has been approved by the Victoria University of Wellington Human Ethics Committee 0000027808.

HOW CAN YOU HELP?

You have been invited to participate because you are a primary, intermediate or secondary school teacher and have experience teaching in New Zealand. If you agree to take part, you will complete a survey. The survey will ask you questions about waste management in the school, student learning in relation to waste and sustainability, as well as questions to discover your thoughts on how 3D printing could be integrated into current learning. The survey will take you up to 30 minutes to complete.

WHAT WILL HAPPEN TO THE INFORMATION YOU GIVE?

This research is anonymous. This means that nobody, including the researchers will be aware of your identity. By answering it, you are giving consent for us to use your responses in this research. Your answers will remain completely anonymous and unidentifiable. Once you submit the survey, it will be impossible to retract your answer. Please do not include any personal identifiable information in your responses.

WHAT WILL THE RESEARCH PRODUCE?

The information from this research will be used in my Masters research portfolio. There is also potential for this research to be used within the context of academic or professional conferences, exhibitions and journals.

IF YOU HAVE ANY QUESTIONS OR PROBLEMS, WHO CAN YOU CONTACT?

If you have any questions, either now or in the future, please feel free to contact either:

STUDENT:

SUPERVISOR:

Plastic in practice:
An empirical approach to 3D printed upcycling in New Zealand schools

Maddison Jessop-Benseman
2020