SUSTAINABLE MAKERS: TEACHING MAKER VALUES

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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MAKING PLASTICS WASTE

As technology continues to increase, its incorporation into one's daily life becomes nearly invisible. This incorporation ranges from a simple electric toothbrush to cellular telephones and smart, self-driving cars. Furthermore, a specific group of technologies, called maker technologies, which includes 3D printers, have become increasingly popular in all age groups. In his financial analysis, Austin Hatley (2013), associate of Street Authority Network, cited a "35,000% increase" in sales of 3D printers in the four-year span of from 2007 to 2011 ("The Next Trillion Dollar Industry", para 23). The term "maker technology" derives its roots in the maker movement. The movement itself consists of a broad spectrum of concepts and values. In paraphrasing Canadian research chair, David Gauntlett, Radford University senior faculty members, Mekolichick and Wirgau (2017), noted the values inherent to the maker movement as, "the do-it-yourself mentality, experimentation, exploration, invention, and spirit of collaboration" (p. 23). The heart of the movement focuses around do-it-yourself, and with an increase in 3D printing, the ability to design newer technologies can become easier.

During the fall of 2019, a group of undergraduate Mechanical Engineering students at the University of Virginia primarily used 3D printers and other maker technologies to design and develop a small robot. The purpose of designing the robot was for it to serve as a potential tour guide in the Mechanical and Aerospace Engineering department (Davenport, Demaree, Hathaway, Rorie, & Sompayrac, 2019, p.3). In their technical paper, the group briefly discussed costs of their project (pp. 9-11) in terms of general budgeting; however, when analyzing Table B1 in Appendix B on page 56, it should be noted that approximately $2000 of 3D printed materials (p. 56) was not factored into the overall cost. These costs included both the final product, which estimates at approximately $400 in 3D printed material, and prototypes, the latter which were either thrown away or set aside as spare parts. By focusing on the end product, the students ultimately ended up contributing to a growing plastic waste problem through the use of maker technologies which is tightly coupled to this Science, Technology, and Society thesis. This raises the questions: how can plastic waste be reduced, and in what manner would be best to incorporate sustainability and maker technologies in an ethical manner? To answer this question, a combination of Pacey's Triangle and Situation in Context will be used to model the key concepts linking sustainability and maker technologies. Then, Actor Network Theory will be used to develop a hand-off model for implementing both maker technologies into education to help instill a sense of sustainability in current and future generations.

BECOMING A PLASTIC WORLD

Plastic waste has been a developing issue since the 1970s. According to "The History of Plastics Recycling", published by the American Chemistry Council (2017), the first public plastic recycling program began in 1972 (para. 2), and that as of 2016, "more Americans are able to recycle more plastics than ever before," (para. 20). While the opportunities and capabilities to recycle have increased, the amount of plastic waste has also increased. As of 2017, at least 6.3 billion tons, of an estimated 6.9 billion tons, of plastic has accumulated as non-recycled waste (Parker, 2018, para. 4). The 91% of non-recycled plastic waste would not be as significant of an issue if all the plastic was biodegradable; however, approximately 399 thousand tons of plastic in 2018 (Sherman, para 6) were biodegradable. This plastic would account for less than 1% of the total plastic accumulation. The resultant of the 99% of non-biodegradable plastic wastes is that they either do not naturally breakdown or will become smaller pieces. This plastic waste is most prevalent in the world's oceans and are known as 'plastic patches'.

Plastic Islands in the Oceans

While the oceans are vast, approximately 70% of the Earth's surface, plastic still accumulates at a rate of approximately 14 million tons of plastic annually enter the ocean (Leventhal, 2018, para. 1). The plastic enters oceanic currents which are capable of circumnavigating the world. A key feature within the currents are large gyres, or circulation zones, within both the northern and southern hemispheres of the Pacific and Atlantic Oceans. Within these sections, the plastic is broken-down into smaller pieces. The Great Pacific Garbage Patch, a well-known area in the northern Pacific Ocean, mostly contains non-biodegradable microplastics (Caryl-Sue, 2019, paras 3-5). Microplastics refer to the micro-size remains of plastics that can be ingested by wildlife and enter the food chain. Although, recycling centers and personal recycling aid in an effort to prevent plastics from being waste or entering oceans, plastic dumping is still a world-wide issue.

Politics of Plastic Trash

The continued push for recycling efforts has increased in the past few decades. The effort has shown that it is important to understand the basic model of a plastic life-cycle. Figure 1, on page 4, illuminates an archetypal model of the plastic life cycle following a simple handoff from creation to implementation. The steps of reuse and recycle within the life-cycle are considered green, or sustainable, in nature thus are colored green to match. The consumer aspects of the life-cycle are labeled in black. While this is an ideal system, it continues to end with the plastic in the trash, but it fails to show the innerworkings of the recycling to raw materials sections.

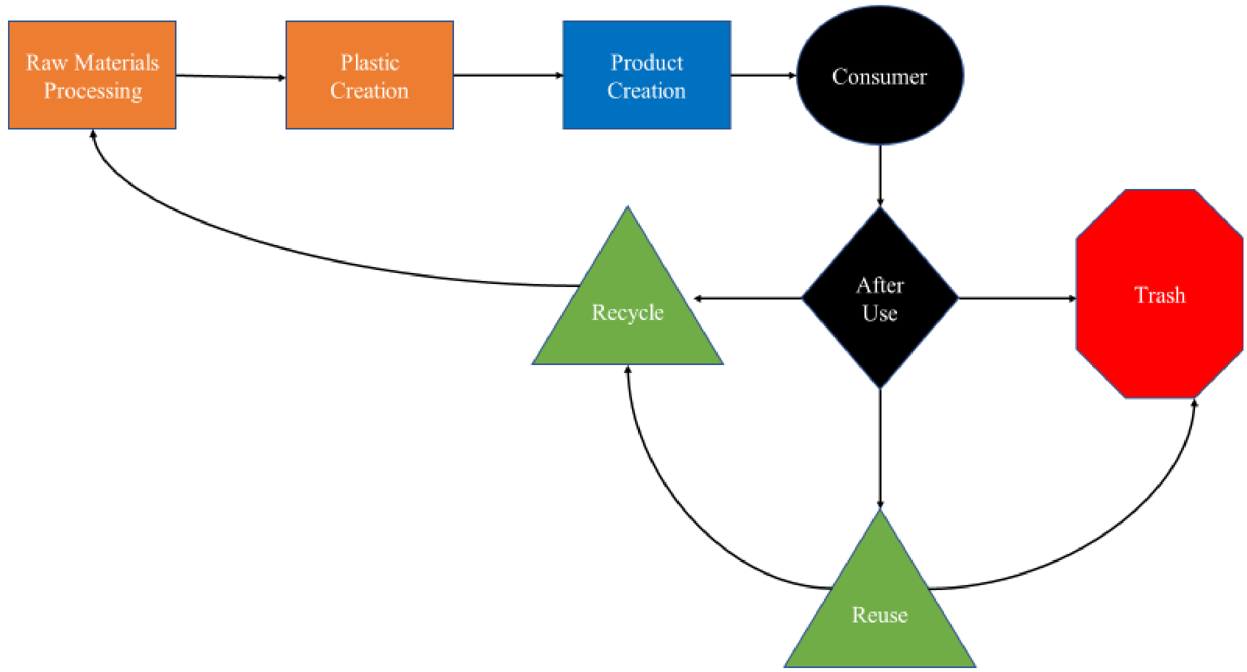

Figure 1: Prototypical Life-cycle of plastic products: Plastic lifecycle based on a simplified handoff model where they end user is left to make a decision regarding their plastic product (Hathaway, 2020).

According to the ENF Recycling website, the United States hosts 221 plastic recycling plants that "process waste into new materials" (2020, para. 1). One issue with plastic recycling, as seen in ENF's chart (2020), is that processing centers only accept certain plastics. Even though these recycling plants exist and are able to create new materials for new products, there is an inherent issue when looking at all plastic recyclers. The aforementioned chart does not list the plastic recycling collectors who outsource the recycling processing to other countries. China was one such country who received recycled plastics for processing; however, beginning in 2016, China stopped importing global plastic waste (Crawford,A. and Warren,H., 2020, paras. 1-2). In blocking the imported plastic wastes, China aided in diverting global plastic recycling importation into other countries. As *Bloomberg* journalists, Alan Crawford and Hayley Warren, explain that the Basel Convention, regulation convention for plastic exports, states that "… only clean, sorted and recyclable plastic…" (para. 9) may be exported; however, more often than not, the plastics contain trash or dirty materials unable for recycling.

In an exposé, the Canadian Broadcasting Company (CBC) Marketplace journalists identified companies in Malaysia who purchase the recycled plastics and subsequently burn the plastics in order to dispose of them (2019). In a follow-up article, Katie Pedersen, Eric Szeto, David Common, and Luke Denne, CBC Marketplace Journalists, (2019) tracked bales of plastic for recycling through three recycling companies revealing that only one company had processed the plastic for resale; while, the other two companies either burned the plastics for power or diverted the plastics to a land fill (paras. 1-31). These issues are not only particular to Canada, but the rest or the world. A larger problem arises when people begin to use plastics in maker technologies, like 3D printers, resulting in single-use items that can be easily thrown away without thinking of recycling.

LACK OF CONSCIOUS MAKING AND RECYCLING OPTIONS

With the increase in curiosity of being able to make virtually anything possible, the question arises: what can one make? 3D printers provide the opportunity for almost anyone to bring their imagined objects and contraptions into reality. Allison Arieff, current editorial Director for the San Francisco Bay Area Planning and Urban Research Association (SPUR) (Arieff, A., n.d., para. 1), analyzed the Maker Movement and its associated technologies for *Medium*. In her analysis, she noted that the Maker Movement failed to instill sustainability (2014, paras. 1-5) and the environmental costs of using 3D printers (paras. 7-8) into its initial users. The author cites two of these costs: an increased power usage of "…50 to 100 more… than injection molding to make an item of the same weight" (para. 9), and increased the need to use plastics. As need and desire for 3D printers increased, the consequences of ease begin to arise. John Tierney, a contributing editor for the City Journal and the New York Times science column (City Journal, para.1; johntierneynyc.com, para. 1.), noted an ethical issue surrounding the maker movement as "… people involved in creating and making things get removed from these bigger concerns…" (2015, para. 18). Tierney's claim brings forth the issue of a production focus versus an eco-centered focus.

Productivity vs. Trash

A key issue that has arisen with the availability and ease of 3D printing is one of personal responsibility. Daryl Koehn, a professor at the DePaul University College and the Wicklander Chair in Professional Ethics noted this issue by claiming:

> "If no such care is taken, there is a risk that producer-consumers will print things willy-nilly…makers may not feel much attachment toward these printed objects; they may begin to see everything as just so much disposable stuff" (2015, p. 14).

The key assumptions that surround Koehn's claim were ones of precedence and disillusion of responsibility. The ease of production provides makers with a manner to establish their own precedence for their creations. Similarly, in questioning the sustainability of 3D printing, Lydia Skrabania (2018), brought forth a similar claim of:

> Being able to quickly and easily produce everything you need (or believe you need) yourself could actually end up dramatically increasing our consumption - if there are limited regulations and a lack of ecological awareness among consumers (para. 3).

Lydia Skrabania is an editor and contributor to the not-for-profit organization RESET ('Lydia', n.d., 'About me'), which focuses on Sustainability. By raising the issue of ecological awareness and regulations of consumers, Skrabania provided potential solutions to instilling personal responsibility in 3D printer users. However, neither of these claims addressed an inherent issue with 3D printing which was the difficulty with using recycled filaments.

Engineered Problems

Two primary types of plastics exist for production: Thermoset and Thermoplastics. Thermoset plastics consist of polymers who, once set, are unable to be remolded; while, thermoplastics retain the ability to be melted and reshaped multiple times (modorplastics.com, 2017, paras. 1-2). According to the article "18 3D printer Filament Types and Uses Comparison Guide" (Allthat3d.com, n.d.), the most common 3D printer filaments are thermoplastics (3D printer filament table). This would mean that the products created with the filaments could be recycled into different products or transformed into a recycled filament; however, continued reuse of filaments may have negative effects on the desired properties of the resultant product. In an analytical study (Lanzotti, A., et al., 2018), Italian researchers discovered that the strength of polylactic acid (PLA) filament decreased by 37% after being recycled three times (p. 145). The study illuminated the issue that engineered plastics only have certain properties after the first use. While the first several subsequent uses had similar properties (Figure 3, p. 145), the resultant properties were lower than the initial use. In terms of recycling 3D printed materials, the issue of not having desired properties could force people to use a material once and then throw it away if it failed to meet give expectations further driving an 3D printing into an unsustainable group. This reinforces the issue of precedence brought forth by Koehn (2015, p. 14), and Skyrabania (2018, para. 3), where users would tend to reprint something rather than recycle. Additionally, they promote the question of how to make 3D printing more sustainable and increase recycling.

APPLYING MAKER IDEALS FOR AN ETHICAL VALUE SYSTEM

Recycling and 3D printer sustainability are becoming points of consternation as previously mentioned. Looking at the Maker Movement ideals and values could provide a possible solution. As the Maker Movement has continued to increase in its associated Maker Faires, Conventions, and numbers of new users, its values continued to grow. One such value is the idea of upcycling, "…the intentional transformation of hard-to-recycle materials into new products" (Schreiber, M., 2016, para. 3), which would promote 3D printer users to reuse their original designs into something new, similar to the reuse section as seen in Figure 1 on page 3. Consequently, this may only delay a large product from being trashed, and could make separating the constituent pieces to be recycled. In order to address these points, the answer could be found in the future. The future being the generations of students in primary, secondary, and collegiate levels of education, and applying the updated Maker Movement ideals to promote an ethical design and production value system. The purpose for looking at the educational system and younger generations was to counteract the age-old claim of "you cannot teach an old dog new tricks"; in other words, there is a need to curb the precedence already established by the technologies. As alluded to by Skyrabania (2018, para. 3), increasing 3D printer regulations, ecological awareness, or both, could aid in making 3D printing more sustainable. However, the manner of including either regulations and awareness, or establishing a standard of awareness was not clear within the article, and the educational system may be the answer.

IMPLEMENTING A FORMAL LESSON PLAN

Traditional education focuses on three main tracks beyond elementary grammar and mathematics: Arts, Science, and Business. Makerspaces and fabrication laboratories, fab labs, provide a mechanism to bring the three tracks together. As suggested by Dale Dougherty, the "godfather of the modern maker phenomenon" according to *Education Week* staff writer Benjamin Herold (2012), hands-on learning could be a more effective way to teach children, as the hands-on method can prevent children from "[being] disengaged and bored in school" (p.12). As the suggestion focuses on children, it could further apply to all students.

Applying the values through the educational system promotes an increase awareness for the costs of printing, and including 3D printing and design concurrently with environmental sustainment, students would be encouraged to develop virtues of intrinsic motivation for creation and sustainability in design. Koehn (2015, p.7) proclaimed that "virtue ethics has long stressed the importance of intrinsic motivation". One major question arises as to how to properly integrate 3D printing and Maker values in order to promote the virtue of intrinsic motivation, and ultimately promote a greater sustainability in 3D printing, and an affinity for recycling to further reduce plastic usage.

Mapping An Analytical Model

A couple key methods for analyzing the connections between Maker ideals, education and 3D printing. In applying the definition of technology and technology practice of Arnold Pacey's Triangle (1983) to the aforementioned connections, figure 2, below, arises indicating the three major aspects of maker technologies. The technical aspect would consist of: 3D printers, design skills and software (p. 6). The organizational aspect consists of: educational institutions like schools, universities, and libraries; governmental

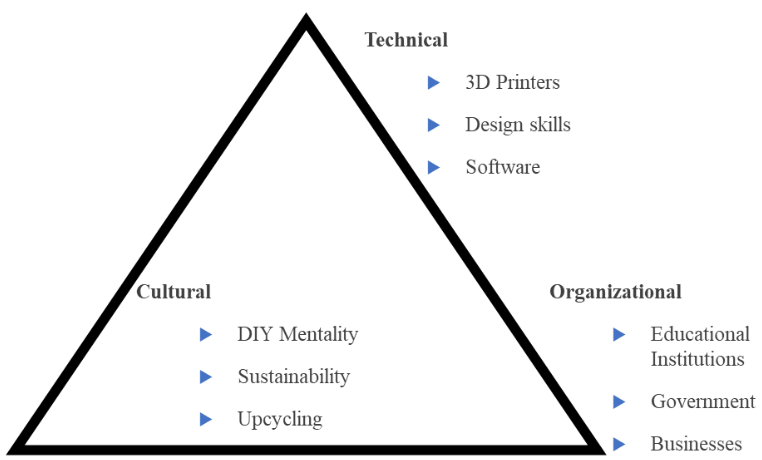

Figure 2: Mapping maker technologies Pacey's triangle: Separating the individual aspects of maker technologies provided a connection between 3D printers, education, and sustainability. (Hathaway, 2020).

organizations in research and development, and funding; business organizations in product development, design, and donation; and hobbyist instructors. The "do-it-yourself mentality, experimentation, exploration, invention, and spirit of collaboration" (Mekolichick & Wirgau, 2017, p. 23) values, and the "need to engage passionately with objects" (Dougherty, 2012, p.11) make up the cultural aspect of maker technologies. By adding the concept of upcycling and sustainability to the values, a context can be set for shifting the focus from the broad spectrum of Pacey's triangle to a narrowed system in context model, as seen in Figure 3. The system analyzed is the use of 3D printers in an educational environment. Individual groups, A through C respectively, include: the educational system, and environment in the center and surrounded the boundary object of 3D printing; teachers and educational staff serve as the gate keeper; students would represent those affected by the results of the system.

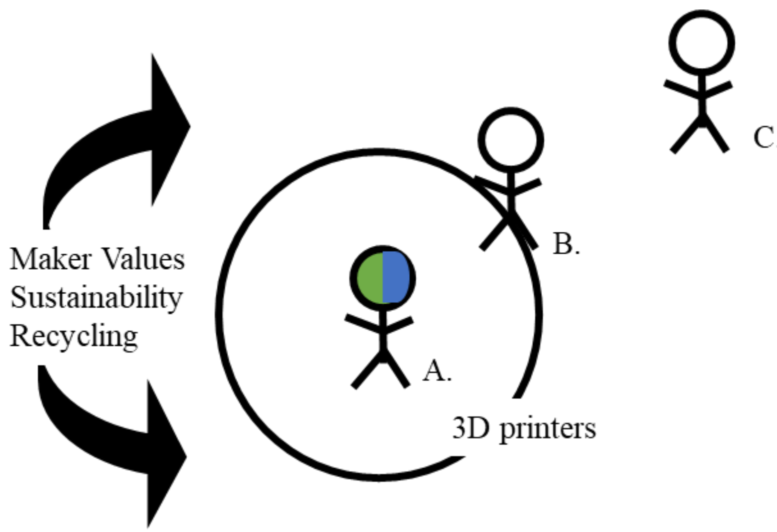

Figure 3: 3D printing and educational system in context: Persons A through C represent those affected by 3D printers (boundary object) and the sustainability context. Those affected include educational system, teachers, and the students, A through C respectively. (Adapted by Russell Hathaway from B. Carlson, 2020).

By using this model, the direct association between teaching staff, 3D printers, students, and sustainability considerations can be seen. This would mean that the impact of teachers would be must larger on students than just implementing regulations. Thus, while this model in

Figure 2 provides a narrower view of the system, it does not provide a manner of how to apply the values within educational systems.

Actor-Network Model for Implementation

The educational system can serve as the apex for instilling values like: sustainability, exploration, and inventiveness. This can be through simple opportunities that students may not normally be afforded. Koehn (2015) noted this advantage in her analysis on the access to "[cutting-edge] technology" (p. 8), which provides small businesses to increase competitiveness between the businesses and large corporations (pp. 8-9). The cutting-edge technology was in reference to Maker technologies such as: 3D printers, laser cutters, and computer numerical control devices. The importance of having access these technologies for small businesses is synonymous to the importance for students.

By adding these technologies, specifically 3D printers, into school lessons and classes, students would have access to technologies that are emerging in the workforce. However, as previously mentioned, sustainability and recycling remain problems surrounding 3D printers. To alleviate these issues, incorporating classes and rewards within the educational system can create more informed users. Figure 4, on page 12, prescribes a handoff model (Carlson, 2009), in which 3D printers and other Maker technologies should be incorporated into educational systems. The handoff model is based on the Actor-Network Theory (ANT). In ANT (Callon, 2007; Law, 1992; Latour, 1996), a network consists of groups of entities considered actors which are interconnected, wherein the actors may have positive, neutral, or hostile affects with regard to each other and the network. Figure 4 depicts the handoff from the Maker Technology, top-left, and ends with students, bottom-center. The actors within this network are arranged in four groups: Maker Movement in black; Educational System in green; Environment in blue and outlined in green; and Students in yellow. The connection between each of primary actors is established at each of the handoff nodes. Also included in these handoffs are exterior actors that affect decisions on subsequent primaries.

The implementation handoff from maker technology to the education system incorporates government legislation, acceptance by educational systems, non-profit organization support, and media coverage. The education system is a crucial part of the handoff model as it involves the hierarchy of schools, public opinion, and funding to accept maker technologies. After which, the incorporation handoff defines how the education system plans to establish settings for maker

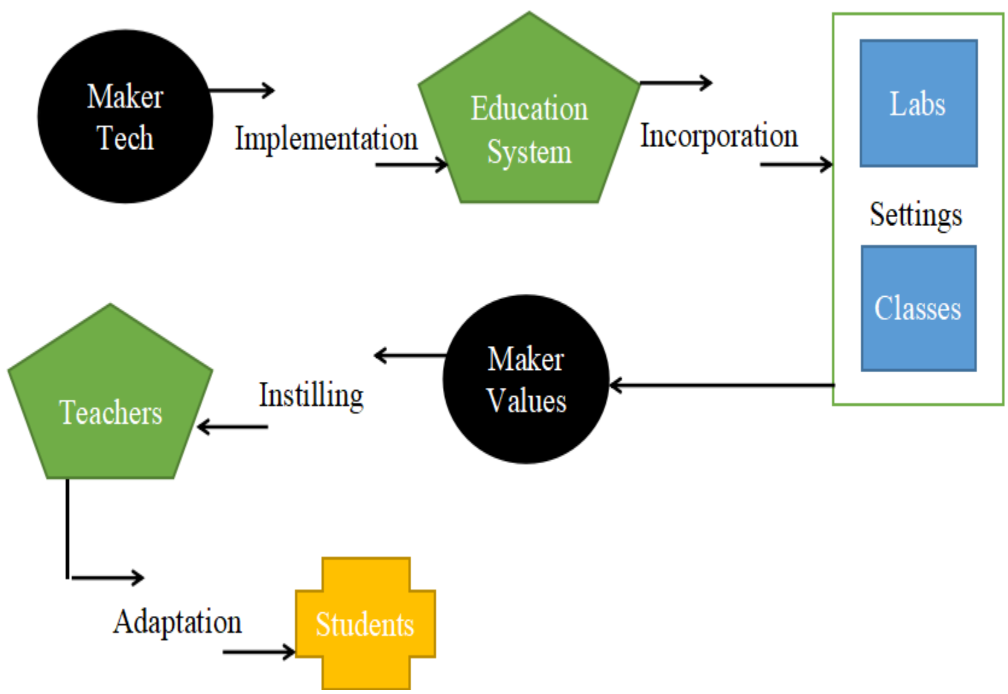

Figure 4: Handoff from maker technology to student: Beginning at maker technology in the top right, the handoff movement flows from top-right to bottom center, the student, incorporating various education levels maker aspects and settings. (Hathaway, 2019).

technologies. This involves design and development of spaces and classes, as depicted by the blue squares, labs and classes in Figure 3, page 12. Both during and after these settings are established, the next handoff is to Maker values. This block serves as a transition point from major concepts and restructuring to individuals. Following maker values, the instilling handoff challenges the status quo of teaching faculty. New York Times writer, Melinda Delkic (2018), specifically noted, in two interviews, that some teachers do not understand the concepts of being a maker and need a period of adjustment (para. 8-9, 12, 14). In acknowledging and understanding the values and concepts of the maker movement, faculty members can adapt and incorporate them into lesson plans and projects, as noted by the adaptation handoff. The final section in this model consists of the student. The handoffs between Maker values and Students are critical points in this model as they fixate on the need for teaching staff and students to connect with one-another.

The connection between teaching staff and students can provide an easy network to educate students on sustainability and recycling, as well as provide students with a reinforced ability to practice and develop products that are sustainable. For example, students at University of Berkley created a recycling program to combat 3D plastic waste on their campus (Brice, 2017, paras. 4-6). By creating a program to combat 3D printed waste, the students expanded their own desire for sustainability and recycling to include the campus as a whole, thus increasing their sphere of influence. It is this ability for individual actors to contribute to and benefit from a network that provides a contrast to the analytical model depicted in Figure 3 on page 10.

Comparison of Models

The scope of the two models, Figures 3 and 4 on pages 10 and 12 respectively, vary in quite dramatic ways. The analytical model, Figure 3, provides a broad understanding of 3D printers, recycling, and the problem with sustainability as it pertains to education as a whole. This provided a basis to develop the handoff model, Figure 4, as derived from ANT. The handoff model provides a narrower scope, as pertaining to education, and allows for a more defined roles that each actor can play. Furthermore, by incorporating exterior actors as envisioned in the Implementation handoff described at the bottom of page 12, the handoff model further enables individual actors to increase their roles. In order to promote recycling, New York University Office of Sustainability awarded $13,572 to its “Design Lab @ NYU MakerSpace… to develop a plastic shredder recycling system…” (NYU, 2019, para. 2). By providing a financial award, the University’s Office of Sustainability incentivized students and faculty members in the design lab to make sustainability, primarily recycling, a priority. The ability to incorporate individual actor adjustments to the system serves as the over-arching benefit the handoff model has over the analytical model. While the handoff model has this benefit, neither model provides a manner of understanding the complications and solutions to plastic waste.

CLOSING THE MODEL ON PLASTICS

Plastic waste is a growing issue. It continues to accumulate in landfills, and in the ocean and these increasingly large amounts entering the ocean has created islands of microplastics. While recycling has aided in curbing the amount which enters as waste, technologies like 3D printers provide an easy way to create more waste. Furthermore, two primary issue arise from 3D printer use: productivity versus ecology, and designed waste. As people tend to focus on availability, they often lack the focus on other issues like recycling old products, and even when the thought arises, the ability to recycle previous prints brings forth another issue of engineered properties.

Thus, these technologies, primarily, served as the driving force to develop a manner of instilling sustainability in younger generations to curb future plastic waste. While the broad issue could be envisioned as a system-in-context (Carlson, 2009), a handoff model could be used to depict a proper manner to teach values in the younger generations through educational systems. By conducting more in-depth research, a better model could be developed; however, the question remains, what would be the best way to instill sustainability as a virtue?

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