DESIGNING A POWERED AIR PURIFYING RESPIRATOR FOR STUDENTS

IMPLEMENTATION OF WEARABLE MEDICAL TECHNOLOGY IN SOCIETY

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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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As the Coronavirus continues to infect millions of people all over the world, the ongoing pandemic's effects still linger within society and our institutions. While attempting to return to schools, workplaces, and everyday life, many feel that we are ill-equipped to contain the spread of the virus, much less prevent future outbreaks. Mask mandates and social distancing guidelines have proven to be effective as long as people follow them, but even the most effective facemasks on the market are not 100% capable of stopping the spread of aerosolized particles. An electrically-powered air purifying respirator system is currently the best option for keeping yourself safe, but they are expensive, bulky, and are predominantly worn in hospitals. These designs only filter the intake and not the exhaust, presenting a danger to everyone else nearby if you have already unknowingly contracted the virus.

We propose a cheaper, powered facemask intended for the general public with end-to-end protection from the Coronavirus and other harmful particles. This would greatly benefit settings like schools and universities, where regulations are easier to enforce. However, we are at a crucial point in history in which engineers need to not only focus on developing solutions, but also be mindful to the integration of their designs into society. Peoples' lives are at stake, so it is vital that we envision all possible effects of the technology before presenting it to the world. In the latter portion of this paper, I will be examining the ramifications of pushing wearable medical technologies into society. A working prototype of our design will be ready by early November, the final design and technical paper will be completed by the end of the month, and the STS research paper will be completed by May of 2021.

DESIGNING A PRACTICAL POWERED AIR PURIFYING RESPIRATOR

Technology has enabled us with everything we need to adapt to life during a pandemic, but as a society we should aim to be proactive with technology in order to eradicate and prevent future outbreaks. Our powered mask will be designed to solve this problem now and for the future. Under the technical supervision of Professor Gavin Garner, my team consists of Noah Rempfer, Jack Herrmann, Dale Midkiff, Jacob St. Martin, and myself. Our goal is to fabricate a cheaper alternative to current technology with an end-to-end approach for air purification.

Compared to other masks, powered air purifying respirators (PAPR) have the best performance. A PAPR, shown in Figure 1 below, is a device that "protect the user by filtering out contaminants in the air and use a battery-operated blower to provide the user with clean air through a tight-fitting respirator" (Liverman et al., 2015, p. 7). The National Institute for Occupational Safety and Health assigns protection factors of safety called APF scores to evaluate air filtration, and PAPRs are by far the safest current technology with an APF of over 100 times greater than a high-performance N95 mask (NIOSH, 2018). Air purifying respirators are effective because they have been developed specifically for individuals in environments where it is crucial to protect and shield them from outside particles. That being said, aesthetics were never a major design consideration, and traditional PAPR technology does not filter the exhalation. Our design will attempt to be an effective shield from aerosolized particles, protect others nearby, and also look aesthetically pleasing. With a

Figure 1. Proprietary PAPR system: Powered air respirator showing belt design with intake tube (*The 3M Company*, 2020)

radial fan bringing outside air in and an exhaust fan for exhalation, a current of airflow will run across the face beneath a clear mask. Filtered material at both the intake and exhaust will give end-to-end protection, presumably resulting in an even higher APF value than traditional PAPRs.

Not all PAPRs require a tight fit, however. An air-tight fit would block anything coming in and out, but this obviously imposes a risk of suffocation. Maintaining a slightly positive pressure overcomes this. A higher relative air pressure inside the mask repels any unfiltered particles from entering the PAPR (CDC, 2015). While maintaining positive pressure, filtered material lining the inside of our helmet and mask would catch any air not following the main airflow, creating an end-to-end filtered system that prevents the user and those nearby.

In order to fabricate our physical helmet design, we will be molding the shape of our mask to a previously formed model. Without an injection molding machine, we had to be creative, so we designed and built our own vacuum former to thermoset plastics as a side project. Vacuum forming involves heating a sheet of plastic and pulling it around a preformed mold using suction (“Introduction to vacuum forming”, 2020). The rest of the materials and machinery used could be found inside the Mechatronics Innovation Learning Lab at UVA. We were also able to order any necessary parts restricted to an expanded $1500 budget funded by the department of Mechanical and Aerospace Engineering and Professor Garner. In order to make a fully functioning PAPR, the electronics, hardware and software will have to work together seamlessly. We have prototyped on a breadboard to experiment with the programming of pressure sensors and radial fans with our microcontroller. After multiple trials and errors, the next step is to combine these into the PAPR with our 5-volt power supply. Other electronic features, such as voice amplification and Bluetooth wireless connection, will then be considered if we have enough time.

For ease of implementation, we have decided to limit the intended audience and design our PAPR specifically for school children. This way, we can hone in on solving a problem that affects one specific demographic within society. For a large-scale problem like this, the cost of production will have to be decreased significantly compared to current technology. The price of cutting-edge PAPRs are often hundreds of dollars, with some eclipsing $1000 ("3M Powered & Supplied Air Respiratory Protection", 2020). This is not impossible, however, as cost-cutting approaches have been taken by other engineers to drive the overall price down. For example, one open source design by Benjamin Hubbard and Joshua Pearce decreased production costs by nearly 90% off of proprietary PAPRs by using a low-cost 3-D printer and other accessible parts with a self-contained firefighter's mask (Hubbard & Pearce, 2020). Rather than adapting and recycling materials to form new devices, most of our work will be fabricated from scratch. Most of our technical considerations remain the same as described before, just on a different scale, and we will try to include additional features geared toward usage in schools. For the technical paper, we intend to write a scholarly article overviewing these features and the performance of our final design by the end of November.

IMPLEMENTATION OF WEARABLE MEDICAL TECHNOLOGY IN SOCIETY

As beneficial as they may initially sound, protective devices like our design and wearable medical technology in general raise ethical concerns about their current and future impacts on society. In order to understand these effects and obtain a clearer view of their significance, one must first examine the reasons for the sudden, accelerated development of this technology. It is important to expand our knowledge on this topic and research this issue now while technology is evolving at an unprecedented rate. It is critical that we begin to piece together solutions now for this STS problem rather than confronting and patching these problems as they appear later.

The framework which I will use to explain the motives behind the development and dissemination of wearable medical technology in society is a general form of Social Construction of Technology. Abbreviated as SCOT, this theory, postulated by Wiebe Bijker and Trevor J. Pinch, argues that social groups directly influence technology at every step of its development (Bijker & Pinch, 1984). One of SCOT's main characteristics is what Bijker and Pinch refer to as "interpretive flexibility." This refers to social group guiding a technology 's development for it to adapt to their needs and reflect their overall values. SCOT opposes the belief that technology is deterministic, or that it develops independently of societal input. Realistically, there is no situation suited for a definitively social constructionist approach or its antithesis, so acknowledging both will provide insights into the motives and outcomes of this field of technology. This generalized SCOT approach will be best suited for analysis of this broad research problem, and it is illustrated in Figure 2 below.

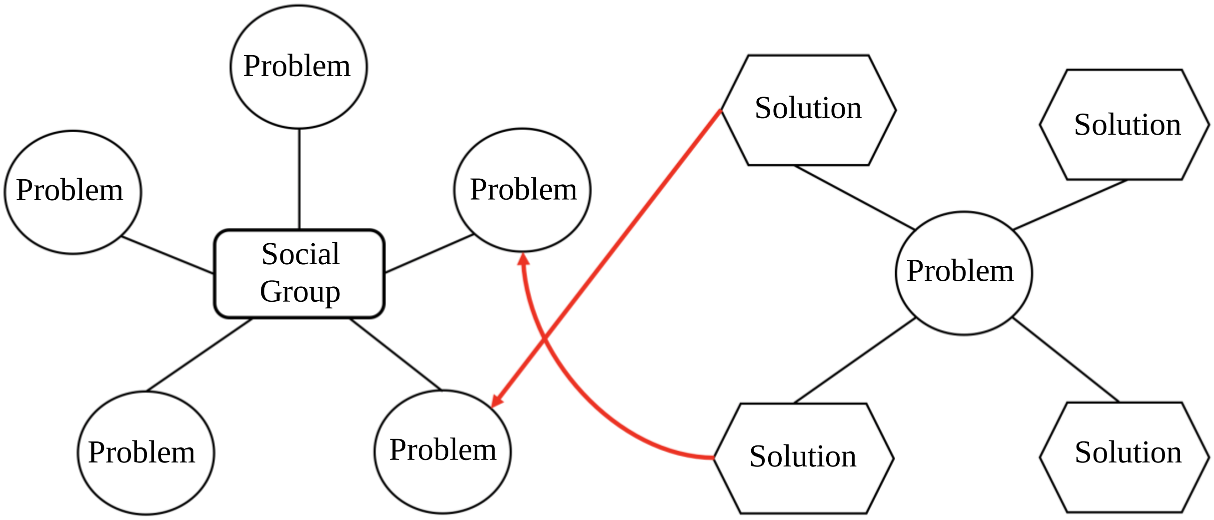

Figure 2. Modified SCOT Diagram: Shows how solutions to one problem can lead to further problems if not fully considering the implications of their design on a social group. (Adapted by Gibiser (2020) from Bijker & Pinch, 1984).

The chaotic linkage of problems that can stem from impulsive technological solutions are evident from the figure above. Problems prompt solutions, but when these solutions could give rise to even more problems, this could lead to damaging, irreversible effects on social groups if not acted upon quickly. Understanding how society drives innovation is important to consider when specifically analyzing a social group's problems. Through the lens of the SCOT framework, it is clear that our society's values of organizational structure and desire for normalcy motivated our team to devise a solution for a particular subset of social groups, in this case school systems. It should be distinguished, however, that the problems themselves prompted the need for a solution rather than the social group directly. Without the overarching problem of a viral pandemic plaguing our world, we would not be developing the design that we are currently spending so much time to make. Interpretive flexibility of the severity of the problem will determine how desperate a social group will be for technological solution such as ours.

Once a problem is identified, SCOT's interpretive flexibility dictates that the social groups' values be represented by the technological solution. This is where moral and ethical decisions need to be made. The first is who gets the supplies in times of need. In dire situations, some would argue that we should distribute all supplies to essential workers, namely healthcare professionals. Carol Taylor, a senior clinical scholar at Georgetown University argues that "when supplies run low, those at the highest risk of contracting COVID-19 should receive the highest priority for receiving scarce PPE" (Taylor, 2020). Distribution of our PAPR technology can also present issues regarding equal opportunity. Age discrimination is a glaring side-effect from our design choice of focusing our technology for school-aged children. Some elderly individuals may not see this as a problem, though. Larry Churchill, a 75-year-old retired bioethicist from Vanderbilt University, explains that "part of the moral meaning of aging lies in a sense of reciprocity across generations" and in the case of shortages, he would resist taking younger individuals' opportunities to new medical technology (Span, 2020). Others, however, may require these opportunities and groups protecting the elderly, like Justice in Aging, will demand fair and equal consideration.

Until a social group can reach a consensus on how to integrate a socially constructed technology, it could be rendered nonoptimal or misused from the eyes of that social group. Because of the rapid advancement of wearable medical technology, we must also consider technology's lasting effect on society. The general form of SCOT does not dismiss this, but incorporates it to heighten the relationship between technology and society. Designing technology capable of altering the way people live, breathe, and perceive the world from inside a purifying helmet begs for ethical questions to be answered if is to be adopted into society. For a direct-to-consumer (DTC) product such as ours, there are no explicit ethical guidelines to follow other than the engineer's discretion. With the possible indirect possibility of affecting user perception and personal interactions, our technology could be classified in a group known as DTC neurotechnologies. These can be broadly defined as products that directly or indirectly augment the brain and are able to be purchased directly by consumers, thus bypassing the health regulations put in place by governmental organizations for clinical settings (Kreitmair, 2019, p. 153). From complex brain computer interfaces to simple smart watch monitoring or social media apps, DTC neurotechnologies like our wearable PAPR clearly have the ability to affect society, but only if society chooses to let it happen. Figure 3 on page 8 illustrates the role of the social group in the innovation process. Examples have supported the notion of the social group being the epicenter of this research problem, implying that a SCOT approach will provide the best framework for my STS research paper.

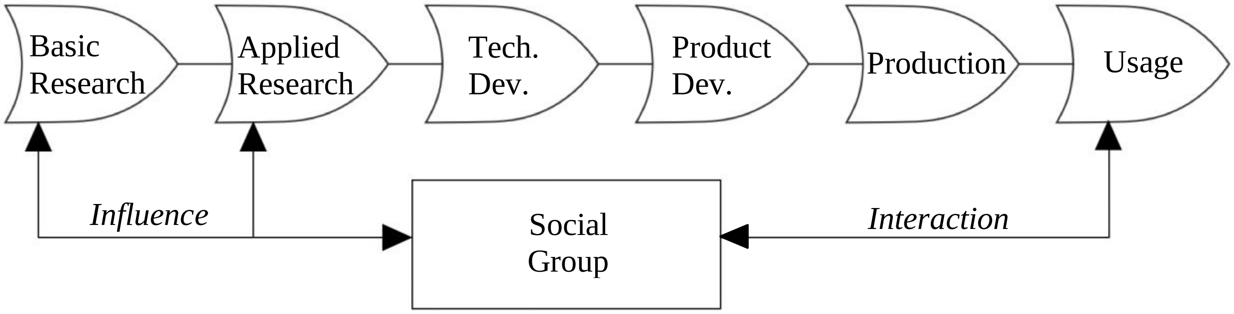

Figure 3. Modified Model of the Innovation Process: Demonstrates the social group's centered role in all stages of technological innovation. (Adapted by Gibiser (2020) from Bijker & Pinch, 1984).

Alternative Approaches

As seen in Figure 2, there could be many solutions to the same problem. Ideally, one or a few solutions would emerge successful and mitigate that social group's need to focus on that problem. Many approaches can be taken and these solutions do not need to be technological in nature. Social guidelines, like universal mask wearing and social distancing, have been proven to be effective when implemented properly: "Countries and cities such as South Korea and Hong Kong, which adopted universal mask wear have much lower COVID-19 incidence, an indirect evidence of its efficacy" (Liu et al., 2020). Maintaining trust in leadership and scientific advice has proven difficult in the United States, however. When considering the organizational trends of a solution's impact on society, an actor-network approach may help contribute to the analysis of the research problem (Law, 1992). By isolating our own design's network, we could more visibly determine the weakest links out of all the possible relationships between stakeholders and actors. A network would only include the users who choose to adopt the technology, and Actor-Network Theory (ANT) suggests that nothing exists outside of the network (Law, 1992). Thus, Actor Network Theory could form a basis for explaining how wearable medical technology like ours is developed and implemented into society. However, SCOT will be the central framework used in the scholarly article which will be written and completed by May 2021, containing my

STS thesis and supporting research of the motives behind expanded development of wearable medical technology in society.

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