MEDICAL DEVICES: THE IMPORTANCE OF ETHIC CODES IN PROJECT DESIGN

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By

Van Spinelli

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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

ADVISOR
Catherine D. Baritaud, Department of Engineering and Society

Optical imaging is a clinical technology used by a broad range of mechanical devices to measure blood oxygen saturation, heart rate, and jaundice progression (Pirovano, 2020). Neonatal jaundice is very common and is caused by a buildup of bilirubin in the blood. Bilirubin is a yellow chemical that is produced when the red blood cells get broken down. This chromophore is normally taken care of by the liver, which processes bilirubin and sends it to the intestines so it can be removed from the body, but the combination of underdeveloped livers and high red blood cell concentration in infants leads to neonatal jaundice. Monitors tend to overestimate bilirubin concentration in infants with high melanin content due to an overlap in the frequency of absorption of bilirubin and melanin (Lamola & Russo, 2015). Because melanin governs skin-tone and is a potent light absorber, this chromophore decreases the amount of light that can be used diagnostically, preventing deeper penetration of image devices (Mantri and Jokerst, 2022). Overestimation of bilirubin levels leads to the infant undergoing phototherapy to treat jaundice for longer than necessary durations which has many negative side effects (Okwundu, 2017).

In practice, these longer phototherapy prognoses are influenced by skin-tone, shedding light on a dissonance in the quality of healthcare received by different ethnic groups. In an attempt to remedy this issue, and to better answer my STS question, timed photobleaching will be utilized in order to create a decay curve for individual patients with specific concentrations of melanin. The team has developed a computational framework in MATLAB that can be adapted in order to determine the optimal photoisomerization wavelength using extinction coefficients and quantum yield of bilirubin and melanin using existing literature.

Common medical parameters used to guide clinical decision making include blood oxygen saturation; blood oximeters report significantly higher blood oxygen saturation levels in darker-skinned individuals; biases results in a 3.2-fold increased likelihood that dark-skinned patients are not diagnosed for hypoxia and thus do not receive supplemental oxygen that they would otherwise need (Sjoding et al., 2020). These disparities in medical treatment illustrate the importance of creating skin-tone inclusive designs and investigating how different political and medical groups respond to racial biases surfacing from technical research. Tightly coupled, the STS component will examine how skin melanin content can change medical outcomes pertaining to pulse oximeter administration. The report will look into optical imaging methods through the lens of Pacey's Triangle and address the question: what are the challenges in addressing a universally biased clinical measurement device. It is proposed in this thesis that granting societal and ethical considerations a more integral role in the design process allows an enhanced prioritization of both risk-benefit analysis and transparency at each design step.

JAUNDICE IN NEWBORNS

Neonatal jaundice occurs in approximately 50% of term and 80% of preterm infants within the first week of life (Queensland, 2019). Jaundice causes the skin to turn yellow due to hyperbilirubinemia which is a buildup of bilirubin in the blood. Careful monitoring of all newborn infants and the application of appropriate treatments is essential since high bilirubin concentrations can cause acute bilirubin encephalopathy and kernicterus (Kemper et al., 2022). Kernicterus is a permanent disabling neurologic condition characterized by the following: choreoathetoid cerebral palsy, upward gaze paresis, enamel dysplasia of deciduous teeth, sensorineural hearing loss, and dyssynchrony spectrum disorder (Perlman, 2018). Phototherapy is completed in 10% of term and 25% of preterm neonates to treat severe hyperbilirubinemia by photoisomerization bilirubin to an easily excretable form (Quensland, 2019).

Glucose-6-phosphate dehydrogenase (G6PD) deficiency, an X-linked recessive disorder that decreases protection against oxidative stress, is now recognized as one of the most important causes of hazardous hyperbilirubinemia leading to kernicterus in the United States and across the globe (Kuzniewicz, 2014). Knowing information about genetic ancestry can help inform the assessment of G6PD risk. Overall, 13% of African American males and about 7% of African American females have G6PD deficiency (Nkhoma, 2009). This data emphasizes the importance of developing skin-tone inclusive designs for the evaluation of hyperbilirubinemia; this greater susceptibility exacerbates the consequences of inaccurate measurement of TSB (Kuzniewicz, 2014).

TAKING AN UNBIASED APPROACH TO BILIRUBIN MEASUREMENT

The current gold standard method used to determine blood bilirubin levels is using serum samples involving Total Serum Bilirubin (TSB), which requires obtaining venous or heel stick blood samples (Shaw & Ohlsson, 2011). This procedure, while accurate, is painful and invasive, and poses a danger to the infant as it is associated with significant increased risk of infection (Pediatrics, 2022). Other risks of heel pricks include puncturing the heel bone or joint disease, which causes damage to cartilage and bone; in order to continuously monitor TSB, nurses must prick the newborns numerous times, a procedure that is often carried out in the previous heel stick site (Shah & Ohlsson, 2011).

Transcutaneous bilirubinometry (TcB) has emerged as an easy, safe, and convenient method for the evaluation of the severity of jaundice, since no invasive procedure is involved (Ebbesen, 2021). However, while there is no debate regarding the efficacy of this method on White babies, monitors tend to overestimate bilirubin concentration in infants with darker pigment due to an overlap in the frequency of absorption of bilirubin and melanin as shown in Figure 1 below (Lamola & Russo, 2015).

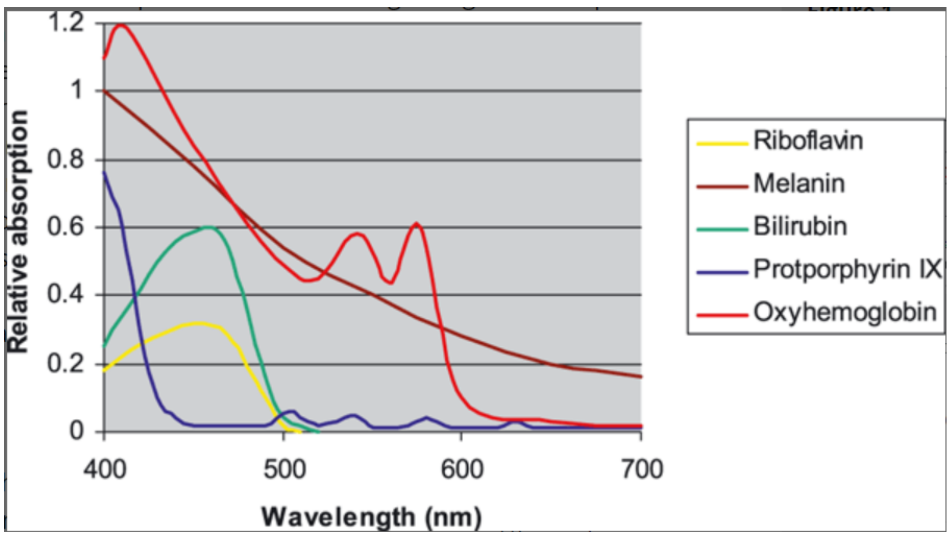

Figure 1: Skin chromophore absorption spectra: Shows the relative absorption of different light energy wavelengths for cutaneous chromophores (Mahmoud et al., 2008).

Light wavelengths used via phototherapy in a clinical setting fall somewhere in the range of 450 to 500 nm; Figure 1 shows biliribun's peak relative absorbance wavelength at 470 nm respectively. The absorbance line for melanin is greater than bilirubin at all points on the graph. There is literature to support that the absorbances of these chromophores are additive such that melanin will absorb photons meant for conversion of bilirubin into lumirubin which the body can readily break down and excrete (Ennever, 2010). For darker-skinned infants, the line for melanin has a significantly larger absorbance spectrum due to the darker pigment. Monitors will thus overestimate the amount of bilirubin due to the significant increase in melanin chromophore content (Onks, 2007).

This overestimation of TSB leads to the infant undergoing unnecessary phototherapy for long durations which has many negative side effects, including depleting essential nutrients, disrupting the thermochemical environment, and needlessly separating the infant from its mother (Okwundu, 2017). The criteria for success of this project is based on the overarching improvements it aims to achieve over current technologies. Most importantly, this involves designing a transcutaneous, non-invasive bilirubinometer that provides accurate values regardless of an individual's skin tone.

The needs regarding the light intensity and wavelength employed are based on their impact on the rate and percentage of photoisomerization of bilirubin in the skin. The wavelength of light used has been shown to significantly impact the proportion of lumirubin formed relative to other byproducts that are more difficult to excrete (Pediatrics, 2022). The light intensity is important because if too low, bilirubin photoisomerization would occur too slowly for the device to work in a timescale similar to existing devices. If the light intensity is too strong, the patient may experience notable damaging side effects (Ebbesen, 2021; Pediatrics, 2022). Considering the absorption spectra of the myriad of components in the skin is essential, as their absorbance spectra overlap with that of bilirubin and impact the quantitative values attained via transcutaneous methods (Mahmoud et al., 2008).

Pulse oximeters are widely used in clinical and nonclinical settings to measure blood oxygenation levels of critically ill, perioperative, and chronically ill patients (Pirovano, 2020).. They work by shining light at two wavelengths: 660nm and 940nm through the skin, which correspond to deoxygenated and oxygenated hemoglobin absorption (Jurban, 2015). The increase in absorption during a heartbeat is measured at each wavelength, then ratio of light absorption at the deoxygenated to oxygenated hemoglobin wavelengths is used to estimate blood saturation level with a calibration curve. Blood oxygenation is used as a threshold for determining the use of supplemental oxygenation as treatment (Jurban, 2015). However, these absorption values are also affected by the relative concentration of other cutaneous contents such as melanin, the chromophore responsible for skin-tone. Melanin has a greater absorption at 660 nm than 940 nm wavelengths meaning greater melanin concentration increases the deoxygenated wavelength absorption baseline (Bicler, 2005). This value gets read by the computer, interprets the smaller increase of absorption, and reports an overestimate of blood saturation level.

The increased estimation of blood oxygen in darker-skinned patients has been observed clinically since the 1990's. Juran and Tobin (1990) found that the target pulse oximeter saturation level of patients receiving supplemental oxygen was 3% higher in darker-skinned patients than lighter-skinned patients because of the overreporting of actual saturation levels in Black subjects. This bias prevents darker-skinned patients from access to supplemental oxygen or insurance reimbursement if those decisions are based on blood saturation levels read from oximeters. But if this literature has existed for over 30 years, why has it taken more than 10 studies and numerous op-ed's for the FDA to finally acknowledge this device bias? (FDA, 2021; Sojoding, 2020).

HOW HARD IS IT TO CHANGE TECHNOLOGY?

This discovery raises many questions regarding the larger network of which this technology is a part. In Arnold Pacey's book on the culture of technology, he defines technology as the application of scientific knowledge to practical tasks by ordered systems that involve people and organizations. In doing so, Pacey examines people and machines to identify the cultural aspects of technology practices which would otherwise be neglected (Pacey, 1983).

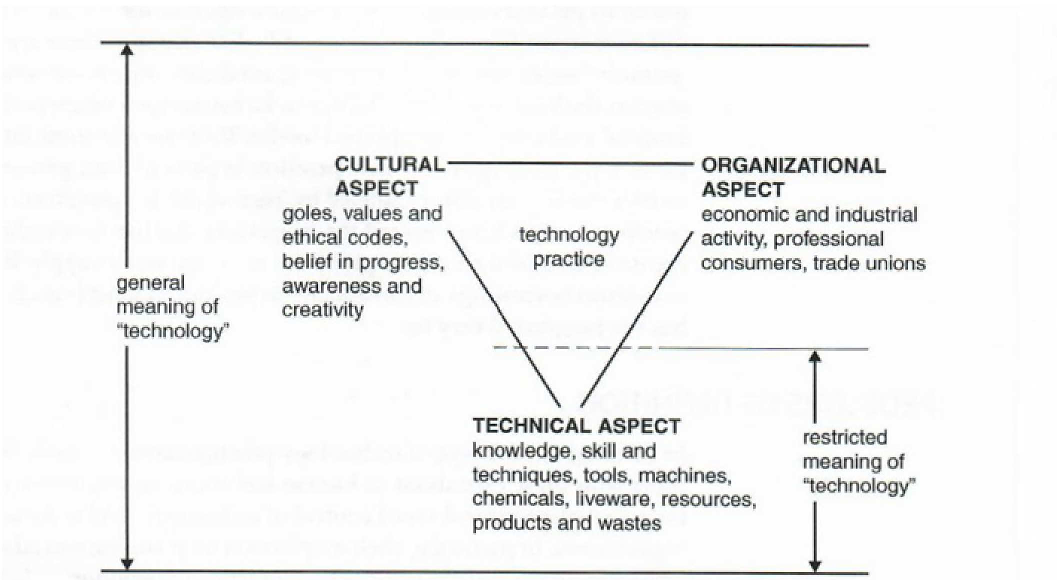

Figure 2: Pacey's Triangle of Technology Practice: identifies the larger network which a particular technology is a part (The MIT Press., 1983).

As shown in Figure 2 above, Pacey illustrates this concept as a triad of aspects that work together to comprise technology-practice. The technical aspect is the aspect that is most often associated with knowledge, skill and technique, tools, chemicals, and the products themselves. The organizational aspect is primarily institutional, with concerns in social and political groups and businesses designed to get things done. The third, and arguably most important aspect, is the culture, which Pacey identifies deals with the ideological aspects of technology, perceptions, and values (Baum, 1994).

Applying Pacey's triangle to optical imaging, the socio-technical intricacies of this healthcare practice start becoming significantly important. If cultural values about progress and beliefs have a major impact on the nature of optical imaging, and if these values are the ones that stand behind discourse that drives technological advancement, why do we continue to see racial disparities in medical devices?

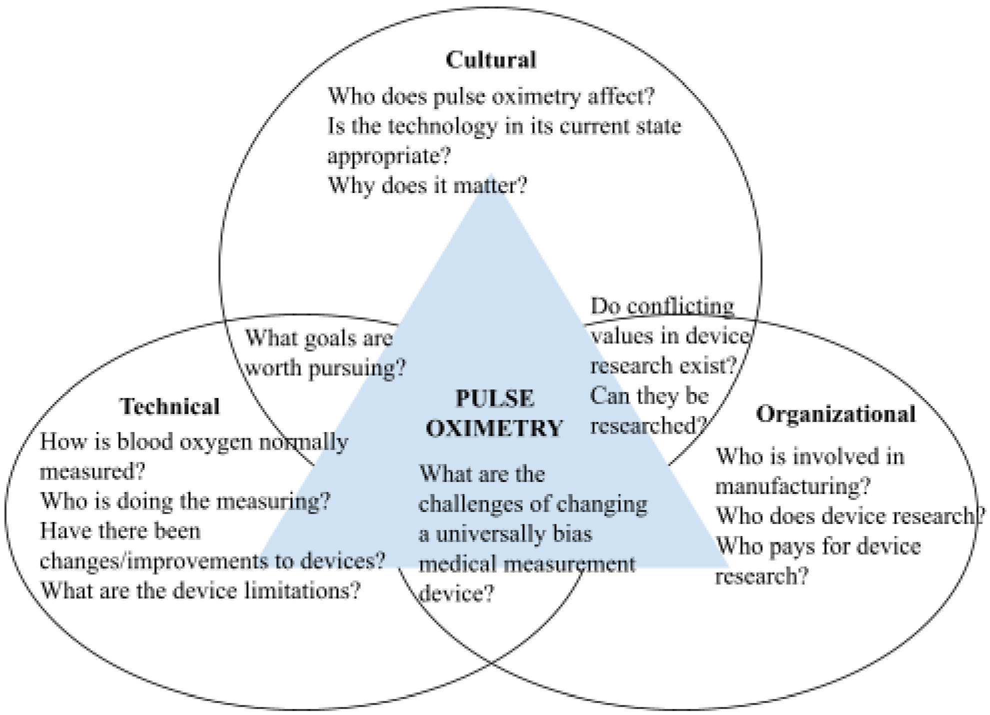

Figure 3: Pacey's Triangle of Technology Practice as a venn diagram: highlights research questions to achieve a fundamental understanding of optical imaging intricacies (Spinelli, 2022).

Questions concerning the values of medical device researchers and the technological goals that would be appropriate to pursue are key to understanding the power dynamics and political commitment to the technocentric narrative of optical imaging technology. While some distinction exists between pulse oximetry and bilirubin measurement, one could argue that both pose many of the same issues viewed through the lens of Pacey's Triangle. Importantly, the Technical group has been exposed to many of the challenges associated with ground work and researching methods in attempting to establish an unbiased alternative to bilirubin measurement;

our experience and relevant anecdotes will transfer over smoothly to the STS analysis. This substantive approach to dismantling the technical apparatus is simple in concept, but has rich applications for tracing power, politics, and mythos in these technologies. In this light, the STS component aims to answer the question: what are the challenges in addressing a universally biased clinical measurement device?

EMPATHY NEVER FAILS

Because biomedical engineering has recently emerged as its own study, as compared to many other engineering fields, it is especially important that we as biomedical engineers be aware of how ethics pertains to our project's development. Transcutaneous bilirubinometry falls under the optical measurement field, and understanding that conflicts of interest, allocation of scarce resources, research misconduct, animal experimentation, and patient populations for clinical trials can all raise ethical dilemmas in the field of biomedical engineering is imperative to consider.

But just considering these notions may not be enough. It is important that these issues are addressed sufficiently for many reasons. Regarding conflicts of interest, understanding the power dynamics and political commitment to the technocentric narrative of optical measurement technology is key to not only the ethical and societal components of our capstone project, but to the field of optical measurement as a whole. As new techniques are employed throughout the development of our new bilirubinometer, financial considerations can often lead teams to simplify their process or technology despite potential negative consequences, such as biasing patients of different ethnic backgrounds. This has been observed: experimental studies tend to be the most expensive, however, a variety of factors may affect these budgets, including the number of project sites and the targeted level of evidence for the evaluation (Zandniapour, 2013). Oftentimes, budget trends are based on whether a project seeks preliminary, moderate, and strong evidence of success and on the program and design factors that influence evaluation budget estimates. It is important to consider that gauging a project's success may be different, and difficult if the implications are, in our case, solving an ethical and ethnically motivated dilemma in healthcare; projects may not receive sufficient funding to conduct the necessary research to solve such problems.

However, that is not to say that spending more on technology to increase its accuracy will necessarily benefit people of all racial groups. The correlation between race and socioeconomic status, and therefore access to healthcare, has been thoroughly studied and reported. In many cases, race and ethnicity can be strong determinants of socioeconomic status (American Psychological Association, 2017). Building an improved bilirubinometer that is financially inaccessible to the community hospitals that regularly serve lower-class populations may only exacerbate issues such as reduced access to care, poorer health outcomes, and increased mortality and morbidity in people of lower socioeconomic status.

The technical aspects that encompass creating a skin-tone inclusive bilirubinometer pose challenges, namely, the discrepancies in dealing with the skin chromophore, melanin. Testing samples that have varying concentrations of melanin, bilirubin, and oxy-hemoglobin to simulate various skin systems is necessary for the success of our project. But melanin does not readily dissolve in solution, and buffers tend to be highly absorbent at wavelengths in the range of melanin, respectively. Put simply, dealing with melanin has a tendency to produce data trivial to our experimentation. This observation has been supported by other studies as well: thorough comparative evaluation of analytical data published so far on melanin analysis has proven to be a difficult task in terms of finding equivalent results, even when the similar protocol was used (Praelea, 2019).

On November 1, 2022, the FDA convened a virtual public meeting of the CDRH Anesthesiology and Respiratory Therapy Devices Panel of the Medical Devices Advisory Committee in order to share information and perspectives about ongoing concerns that pulse oximeters may be less accurate in individuals with darker skin pigmentations. Taken directly from the FDA: "[the FDA] has been working on additional analysis of premarket data, as well as working with outside stakeholders, including manufacturers and testing laboratories, to analyze additional post market data to better understand how different factors including skin pigmentation may affect pulse oximeter accuracy" (FDA, 2021). While it seems we may be moving in a more ethical direction from these statements, simply stating that data will be analyzed does not do enough for the sociotechnical future of optical imaging.

This thesis proposes a design process aimed to more effectively promote transparency in medical device development; the sequence must incorporate the assessment of societal and ethical considerations, but sequenced as a more integral facet. The arrangement of tasks is better depicted in Figure 4 on the following page.

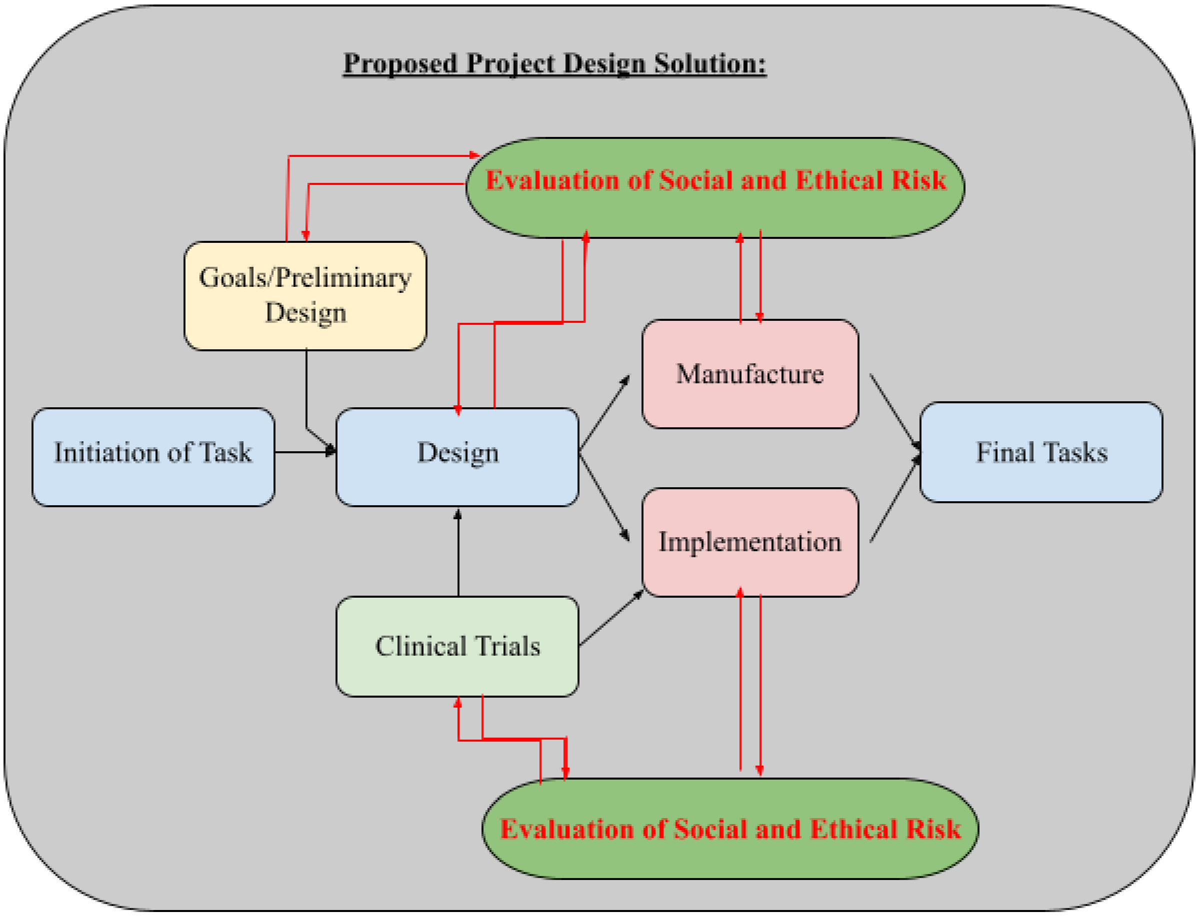

Figure 4: Medical Device Design Process: The evaluation of social and ethical risks illustrated as a more integral facet of the project design process (Spinelli, 2023).

The steps and arrows shown in black represent aspects of a general engineering design process adapted from Martin and Schinzinger's Code of Ethics for Engineers (2009). Importantly, the evaluation of social and ethical implications and associated arrows shown in red highlight the crosstalk between aspects as advised by this thesis. By granting the assessment of ethical codes a more fundamental role in the design process allows for enhanced prioritization of both risk-benefit analysis and transparency at each design step. Revisiting the unintended consequences posed throughout the development and implementation is imperative to the sociotechnical narrative of a project and its subsequent success.

Such reconsiderations of earlier tasks do not necessarily start and end at the same respective stages during subsequent passes through preliminary-design, manufacture, and implementation. This is because the retracing is governed by the latest findings from current experiments. But more importantly, incorporating moral, societal, and ethical implications as an intricate aspect of the design process motivates this notion of responsibility. Projects are ridden with crossroads where difficult decisions need to be made; frequent revisiting of the implications of design, manufacture, and implementation choices must be conducted. While this sounds simple in concept, when temptations and pathways towards convenience arise, it becomes more important than ever to maintain ethical practices.

In 1993, an architect named Bill LeMessurier faced an ethical dilemma: his building required strengthening but doing this would have been disruptive and expensive, and exceeded the insurance he carried (Morgenstern, 1995). LeMessurier faced an ethical dilemma involving a conflict between his responsibilities to ensure the safety of his building for the sake of the people who used it, his responsibilities to various financial constituencies, and his self-interest. According to a conversation with LeMessurier, the architect at last realized that only he could prevent an eventual disaster by taking initiative (Thorton, 1993). This short anecdote highlights the predicaments that engineers face when overseeing a project that has a large area of effect. Changes made during one stage of the decision will not only affect subsequent stages but might also require a reassessment of prior decisions. Dealing with this complexity requires close cooperation among the parties involved in a project's development.

The literature showed some striking opinions about the relevancy of empathy in engineering education. Faculty interviews highlighted that empathy was, amongst other themes, valuable, but not absolutely necessary. One participant stated that "it's [empathy] not part of the engineering culture" (Strobel, 2013). The literature showed that faculty participants stated while empathic skills are "very, very important" it is not a teacher's job to prepare students to be empathetic or caring, continuing that "we don't need a course on it" (Strobel, 2013). It's this type of diction that highlights a serious need for empathy and compassion in the field of engineering.

CHANGING THE SOCIOTECHNICAL FUTURE

Humans are hardwired to empathize but we face quandaries every day when put in perplexing situations. One would hope that we as humans will show empathy and compassion towards others, but as engineers, we cannot rely on hope; we are defined by our actions and decisions, and with regards to optical measurement, specifically, transcutaneous bilirubin measurement, our project is addressing ethnic disparities. But empathy and compassion have been woven into the field of optical measurement due to the notion that the techniques involved offer minimally or non-invasive methods to monitor the inside of the body. More specifically, the idea that the field eliminates the need for painful procedures that would otherwise be used to obtain detailed data on organs, tissues, cells, and even molecules, displays, on some level, an inherent compassion and caring for others.

Even within the external measurement field, we will incorporate empathy and compassion into the creation of our device by understanding the current procedure and the problems with the proctor. Understanding where the patients and the families want change and equality will allow us to address those problems completely. With regard to the future implications of our project, it is essential that we be cognizant of how we address ethnic individuals for clinical testing. We believe it would be beneficial to inform them of the motivation behind our capstone project, and the ethnic disparities we aim to address.

In order to form more robust understandings of the nature of technology controversy, the causes of scientific and technological change, and the limits of rational analytic methods in characterizing complex problems, it is necessary to identify human and non-human actors influencing a technology's progress. Optical imaging devices have existed long enough for STS frameworks to establish motivations for production; Pacey's Triangle can offer an avenue for answering questions regarding challenges involved in technological change. But answering these questions may not be enough. The mission of the STS and Technical components of this prospectus is to empower and motivate the next generation of engineering professionals so that they are capable of making creative, ethical, and inspired contributions to the design of our socio-technical future.

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