Sustainable and Inclusive Engineering: The Use of Mentors and Sustainable Remediation to Increase the Presence of Underrepresented Groups in Engineering

by

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THESIS

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DEDICATION

To my mom, Alexandra Walters

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LIST OF ABBREVIATIONS

BME	Biomedical Engineering
CEHRD	Centre for Environment, Human Rights, and Development
CRAC	Community Representative and Advisory Committee
DST	Decision-Support Tool
E4SJ	Engineering for Social Justice
EJ	Environmental Justice
EPS	Engineering Problem Solving
HYPREP	Hydrocarbon Pollution Restoration Project
LGA	Local Government Areas
RRI	Responsible Research and Innovation
SDN	Stakeholder Democracy Network
SRE	Socially Responsible Engineering
SR	Sustainable Remediation
STEM	Science, Technology, Engineering, and Math
UNEP	United Nations Environmental Program

ABSTRACT

The recruitment and retention of underrepresented groups in engineering, such as women, has been a priority for many decades to diversify the profession to meet the current demand for engineers. Unfortunately, barriers continue to inhibit the recruitment and retention of underrepresented students in engineering, thus reducing the impact of these efforts. A potential barrier is the lack of social connection to the technical problem definition, design, and decision-making that engineers utilize, prioritizing technical knowledge over social. Previous research has theorized that incorporation of social considerations in technical engineering design increases interest in engineering for underrepresented groups.

The purpose of this thesis is to challenge the scope of traditional engineering in efforts to improve the retention and recruitment of underrepresented groups to increase the diversity and inclusivity of the profession through the development of education outreach programs and integration of socially and environmentally just principles into sustainable remediation. The recruitment of women to engineering can begin at the middle school level through the incorporation of an informal outreach program that uses college student mentors partnered with middle school mentees to promote STEM attitudes and challenge stereotypes surrounding engineering identity. Middle school aged girls who participated in STEM mentoring programs over the course of several semesters saw increased growth in STEM attitudes. Through similar programs, students can be exposed to the ways that engineers can directly achieve societal good with the communities they work in. Additionally, these same underrepresented groups can then be retained through specific integration of socially just design focused on community involvement in the decision-making

process. Application of social context can and should be done in engineering projects through environmental justice and sustainability indicators. Through examining a case study in Ogoniland, Nigeria, a framework for evaluating remediation project using adapted social indicators and procedural justice can account for engineering projects in complex social contexts, such as polluting informal economic livelihoods.

The findings of this thesis demonstrate how engineering stereotypes can be challenged both in identity and in the profession, challenging the dominant image of engineering. This work provides the necessary foundation for potentially addressing a barrier in the recruitment and retention of diverse perspectives interested in achieving global societal good.

CHAPTER ONE: INTRODUCTION

Engineers have long been involved in the development of communities by playing a significant role in the shaping of societies and the environments surrounding them (Gaynor & Crebbin, 2013; Lucena et al., 2010). The designs and decisions made by engineers often have lasting ethical implications with the responsibility of engineers more recently being called into question (J. Smith et al., 2014; J. M. Smith & Lucena, 2020). Engineers work with complex "human-technology-environment systems" that require the equal consideration of all the dimensions when making design decisions (Gaynor & Crebbin, 2013). Unfortunately, this equal consideration is not currently reflected in the traditional technocentric decision-making process, perpetuating the harmful stereotype of engineers as being technocratic beings.

This unequal consideration in the decision-making process begins at the institutional level where engineers are trained to solve problems within a set of determined boundaries that are assumed through a systemic procedure titled Engineering Problem Solving (EPS), which does not consider the context of the presented problem (Downey & Lucena, 2018; Gaynor & Crebbin, 2013). EPS draws a sharp boundary around the scope of work that is considered "engineering" by having an engineer define the given information, create abstract idealizations for visual reference, make clear assumptions, identify and apply scientific principles usually through learned equations, and finally, provide a single solution as shown in Figure 1 (Leydens & Lucena, 2009). Problem definition is decontextualized with the EPS detaching the technical dimensions from the social, causing engineers to underestimate the complexity of sociotechnical solutions (Leydens & Lucena, 2018; Niles et al., 2019). EPS has also contributed to the harmful stereotype of engineers by requiring them to behave methodically without passion or impulses, socially separated, technical, and inflexible through embodying this systemic process both in their own work and social life to succeed in their education (Downey & Lucena, 2018; Leydens & Lucena, 2018).

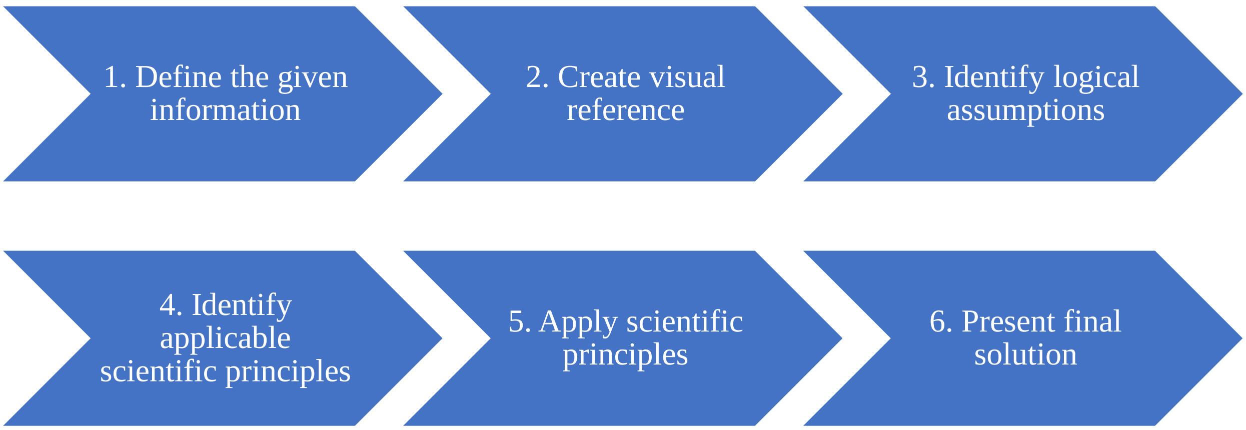

Figure 1: The engineering problem solving process is used by engineers to solve problems within a set boundary around defined measurable information. It does not allow for the contextualization of qualitative knowledge, prioritizing the use of scientific knowledge to produce solutions.

EPS has been cited as a barrier for engineering students to continue their aspirations and passions of helping people through engineering (Downey & Lucena, 2018; Leydens & Lucena, 2009). This is especially important to note as many underrepresented groups, such as women, have expressed greater interest in helping solve greater societal problems related to issues such as poverty to directly improve the lives of others (Bossart & Bharti, 2017; Shealy et al., 2016; Silbey, 2016) rather than traditional engineering problems that are detached from social concerns. The engineering disciplines that are getting close to closing the gap of gender disparity is biomedical engineering (BME) and environmental engineering, where women account for 45.4% and 50.6% of bachelor's degrees (Roy, 2019). BME is the combination of both technical and social considerations, requiring biomedical engineers to be collaborative and interdisciplinary, appreciating multiple perspectives (Gutierrez et al., 2017). Environmental engineering shares some of these similarities with BME as the profession is directly related to human welfare and environmental health but does fail in properly retaining women in the workforce due to lower income opportunities in comparison to other engineering fields (Oerther et al., 2022). The lack of connection between highly technical design and deeper societal concern can ultimately perpetuate the lack of diversity of the engineering workforce.

The history of engineering education and ultimately the engineering profession/identity in the United States has influenced the modern-day approach to decision-making and stereotypes of engineers. Defining who an engineer is and what an engineer does has major implications on the success of diversifying the profession, reducing the gender disparity in engineering, and making engineering more responsive to the people it seeks to serve. This thesis seeks to improve the recruitment of underrepresented groups in engineering through the introduction of non-stereotypical engineers to the incoming generation with purposeful mentorship and informal outreach, as well as improve the retention of underrepresented engineers by integrating environmentally just principles into sustainable remediation indicators by focusing on the inclusion of marginalized communities' voices.

Background

History of Engineering Education: The Modern Day Scope of Engineers

Professional engineering, as understood today, was deeply rooted in transformation of nature into controlled systems to develop and expand empires and colonies through the 18th and 19th centuries. This trend continued throughout the 19th and 20th centuries, as engineers began to develop national identities focusing on nation building of infrastructure without concern of the environment or communities that were affected. The goal of many engineers during this period was to establish order to achieve progress, which, at times, included socially engineering communities to fit this order by moving or redrawing boundaries without consideration for language or culture. The act of social engineering communities continued until after WWII with the emergence of international development (Lucena et al., 2010).

International development was coined in 1947 by President Truman, which was ushered in by the ideology of modernization. Many believed that it was possible to develop and modernize the world through science and technology (Lucena et al., 2010; Rist, 1997). The rise of technocrats began with engineers integrating technology to control and manage social systems with natural resources to be exploited in the name of modernization. This was egged on by the Cold War between the USSR and US in efforts to contain the expansion of the other. Engineering education was also affected by the Cold War as the curriculum became scientized, focusing on the fundamentals of engineering, like what we see today (Downey & Lucena, 2018; Lucena, 2005).

Engineers began to be viewed as important actors in the economic competition between the US and the global stage, shifting the education to have emphasis on the technical and scientific courses, introducing fundamentals such as the engineering sciences and dismissing the social sciences as distractions (Downey & Lucena, 2018; Lucena, 2013; J. M. Smith & Lucena, 2020). This shift continues to be seen in the modern-day curriculum of engineering students across the US (Downey & Lucena, 2018). Due to the scientification of the engineering curriculum, the scope of an engineer has widely remained the same since the shift. The scope remains predominantly technical looking at technical feasibility and costs as the primary metric of analysis with little inclusion of social context into the decision-making process. Some progress has been made in attempting to include communities in the last two decades with the rise of engineering to help activities such as Engineers Without Borders (EWB) and the focus on sustainability, but it still lacks the need for engineers to understand the complexities of sociotechnical design.

Engineers as Technocrats: Barrier to the Recruitment and Retention of Underrepresented Groups

Engineers are trained experts in applying EPS, relying heavily on their technical backgrounds and skillsets, while their social understanding of problems are demoted to afterthoughts (Burack & Franks, 2004). Technocentric elements of engineering can act as a barrier to the inclusion of underrepresented groups in engineering, such as women and people of color. Very few studies have linked sociotechnical thinking and the recruitment of women in engineering. Based on a recent survey on the perceptions of male and female undergraduates, female students placed a higher value on the sociotechnical dimension while also seeing social concerns and responsibility being within the scope of an engineer more so than their male peers (Swartz et al., 2019). One social theory proposed as to the reasoning for more men in these technical fields could come from a difference in personalities and engineering attracts a certain personality that is commonly seen within men (Kahsar, 2019). Given the survey responses from Swartz et al., 2019 study, it is likely that the presence or absence of social considerations in engineering design can influence someone who is underrepresented to remain in the engineering field.

Engineering education reinforces these ideas that engineering is purely technical with decontextualized problems that over time in the program, disengages students from their initial values to public welfare and socially conscious engineering (Cech, 2013). This disengagement then causes tensions within students, prompting feelings not belonging (Brewer et al., 2015; Meyers et al., 2012). There are several ways that this style could be amended to be better conducive for integrating social considerations into designs which includes introducing cooperative learning, problem-based and project-based learning, case-based learning, and service learning (Swartz et al., 2019). The National Academy of Engineers describe what their vision of an engineer would look like in 2020, stating

> "We aspire to engineers in 2020 who will remain well grounded in the basics of mathematics and science, and who will expand their vision of design through a solid grounding in the humanities, social sciences, and economics (National Academy of Engineering, 2004)."

The education of engineers needs to be properly widened to prepare them to properly deliver both sustainable and just engineering decisions that are not purely based on their technical understanding (Conlon, 2008). Some progress has been made to include this expansion as a requirement of ABET accreditation requiring students in engineering degrees to learn how to both properly apply engineering design and recognize the impact of engineering solutions in the context of global, economic, environmental, and social dimensions (ABET, 2021).

Engineers are typically seen as problem-solvers who are strictly rationale by applying their learned knowledge, training, and expertise to develop and implement solutions, relying on their technical abilities (Burack & Franks, 2004; Goldberg, 2015). The idea of who an engineer is and what an engineer does is changing as the need for more socially competent and responsible engineers are made apparent (Conlon, 2008; Goldberg, 2015; National Academy of Engineering, 2004). Students who are interested in societal welfare are marginalized in engineering education, forced to grapple with the undermining of their social values as their technical knowledge is valued (Niles et al., 2019). As students struggle with these values, so does their sense of belonging in engineering, threatening their motivation to continue in their studies.

Research Objectives

This thesis challenges the scope of traditional engineers that is based in technocentric ideology and instead encourages a more holistic robust scope that is based in sustainability and resiliency for community wellbeing. In doing so, engineers will no longer be seen as removed from the social context of design and decision-making, potentially improving the recruitment and retention of underrepresented groups in the profession. This thesis attempts to answer the following research questions:

- How can current engineering stereotypes be challenged to promote the recruitment of underrepresented groups in STEM?

- How can principles of environmental justice, specifically procedural justice, be integrated into sustainable remediation to challenge traditional engineering problem-solving?

The first question focuses on the current engineering stereotypes that can be challenged through community outreach and informal education programs, such as the one presented in Chapter 2, which utilizes engineering students to act as mentors with school-aged students to promote engineering. The mentor-mentee relationship can challenge the students' perception of engineering by introducing the social considerations that engineers make within the social context of engineering problem solving. Throughout discussions of what an engineer does, younger students can learn the direct impacts that engineers have on societal issues with examples provided from organizations such as Engineers Without Borders.

The second research question focuses on how environmental justice, specifically procedural justice, can be integrated into sustainable remediation. This research question is explored in Chapter 3 through the incorporation of procedural justice to sustainable remediation social indicators to provide a more robust and holistic sustainability assessment for remediation projects. The adapted indicators provide a mechanism for engineers to think deeper about societal issues surrounding communities, such as those who are reliant on polluting informal livelihoods, and how engineered solutions can be modified with social considerations to help those communities.

Thesis Structure and Coauthor Contributions

This thesis is organized as follows: Chapter 2 focuses on challenging engineering stereotypes through outreach programs focused on middle school students utilizing a mentor-mentee relationship with engineering students. This paper was originally published as "Promoting STEM Interest in Middle School Girls Through Strategic Engagement with College Student Mentors" as a conference paper in the American Society for Engineering Education Annual Conference and Expo (2022) with coauthors Kathleen Smits and Michelle Schwartz. Kathleen Smits contributed to this manuscript through supervision, editing, and funding acquisition. Michelle Schwartz contributed to this manuscript through supervision and editing. This paper has been reproduced with the publisher's permission.

Chapter 3 presents how the traditional scope of an engineer, in the context of an environmental engineering, can be challenged in remediation by adapting sustainable remediation social indicators utilizing procedural justice principles. This paper was submitted as "Applying Procedural Justice to Sustainable Remediation Social Indicators for Developing Countries with Informal Economic Livelihoods: A Case Study" in the *Journal of Environmental Management* with coauthors Jessica Smith, Michelle Schwartz, and Kathleen Smits. Jessica Smith contributed to this manuscript through supervision, brainstorming, and editing. Michelle Schwartz contributed to supervision and editing. Kathleen Smits contributed through initial concept brainstorming, supervision, funding, and editing.

Finally, Chapter 4 presents the conclusion of this research and proposed the ways forward to advance and apply this research. This chapter will also highlight the novelty of this research and its contribution to the science of challenging the dominant image of engineering and challenging the technocentric engineering problem solving process. By doing so, potentially, increase the diversity of the future workforce to bring new perspectives and innovative solutions.

Scope

It is important to note the limitation and scope of this thesis. Issues regarding gender disparity and racial disparity in engineering has different factors contributing to these issues of recruiting and retention in both post-secondary education and the workforce. Some of these issues include discrimination and institutional policies that can project negative experiences on an individual that will affect their sense of belonging. The incorporation of social considerations into engineering decision-making cannot address those issues directly. It could potentially open up dialogue on how to improve these issues by speaking to underrepresented groups that occupy these spaces currently, similar to speaking to a community, to better frame the problem and work together to develop an implementation plan, both in the workforce and post-secondary education.

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CHAPTER TWO: PROMOTING STEM INTEREST IN MIDDLE SCHOOL GIRLS THROUGH STRATEGIC ENGAGEMENT WITH COLLEGE STUDENT MENTORS

Nathaniel L. Steadman, Kathleen M. Smits, Michelle Schwartz

Steadman, N. L., Smits, K. M., & Schwartz, M. (2022). Promoting STEM Interest in Middle School Girls Through Strategic Engagement with College Student Mentors. *ASEE Annual Conference & Exposition in Minneapolis, Minnesota*.

Abstract

Research on gender differences in career interests has found that by adolescence, girls are reported to be less interested in science and engineering than boys. The leaky pipeline is a popular simplified metaphor to describe the reasons for the observed gender disparity, slowly removing potential candidates from science, technology, engineering, and mathematics (STEM) as they age through the academic system. Although numerous formal and informal programs have been developed to "plug" this leak with role models, what is not well understood is the potential role models' effect on student's STEM attitudes over time. To address this limitation, a long-term continuous mentoring and tutoring program was developed for a local middle school in Denver, Colorado in partnership with STEM focused college students at Colorado School of Mines. The goal of the program was to understand the influence of STEM centered activities and mentors on middle school girls' self-identified STEM attitudes. The program included the revamping of a currently operating science club, one-on-one mentoring, science and math tutoring, and the development of mentor-protégé relationships that was observed to benefit not only the middle school students but also the college mentors. The program did not require the students to apply for any of the services and had access to a diverse group of primarily STEM female mentors. Over the two year period, students participating in the program and a control group of non-participants were surveyed using an amended S-STEM survey developed by the Friday Institute for Engineering Education at North Carolina State University. The general student body's perceptions decreased over time towards STEM between 6th and 8th grade for both boys and girls; girls had lower STEM attitudes when compared to their male peers. Girls who participated in the program over the course of at least two semesters saw an increase in their STEM attitudes while those who did not participate saw a decrease over the multiple semesters of surveys. Exposure to STEM through

general enrichment opportunities did not show a measurable correlation with interest and participation in STEM. Rather, the biggest indicator of STEM interest was access to STEM role models either at home or through access from the enrichment programs. Findings from this work confirm the selection of role models involved in mentoring is vitally important when promoting STEM in education outreach programs.

Introduction

Women continue to be underrepresented in science, technology, engineering, and mathematics (STEM) fields despite decades of focused career promotion through formal and informal education (Aschbacher et al., 2010; González-Pérez et al., 2020; Liben and Coyle, 2014). In 2017, women accounted for 29% of science and engineering employment, representing 27% of the jobs in computer science and mathematics, 16% of the jobs in engineering, and 29% of the jobs in physical science (National Science Board, 2020). Policymakers, educators, and researchers are especially interested in addressing gender equality in STEM (Aschbacher et al., 2010; Campbell et al., 2007; Chesler et al., 2010; Ilumoka, 2012) because of the weakening ability of the United States to compete in the global economy (Aschbacher et al., 2010; Hill et al., 2010; Jayaratne et al., 2003; Knezek and Christensen, 2020; Robson et al., 2020; Terrell et al., 2019) as the demands for qualified professionals are unable to be met in the United States (Aschbacher et al., 2010; Heilbronner, 2011; Jayaratne et al., 2003; Shin et al., 2016).

The leaky pipeline is a popular simplified metaphor used to describe the reasons for the observed gender disparity in STEM careers in literature with the “leak” being reported to begin in middle school (Agee and Li, 2018; Aschbacher et al., 2010; George, 2000; Jayaratne et al., 2003; Kloxin, 2019; Knezek and Christensen, 2020; Mattern and Schau, 2002; Sheltzer and Smith, 2014; Terrell et al., 2019). There are some critiques regarding the use of this pipeline, specifically due to its oversimplification that has narrowly codified the pathway of a STEM professional. The pipeline fails to include those who are not traditionally considered, such as students who are of lower socioeconomic status, or those who were not originally interested in math/science courses during their time in secondary school (Cannady et al., 2014).

This attrition is primarily due to stereotype threat (Cheryan et al., 2011; Hippel et al., 2015), poor educational structures (Goodwin et al., 2014; Stokes et al., 2017), and incompatible identities (Aschbacher et al., 2010; Shin et al., 2016). Stereotype threat is defined as a "social psychological threat that arises when one participates in an activity that shares a negative stereotype" (Hippel et al., 2015). Poor educational structures in this paper are defined as the lack of resources of time, money, and qualified teaching professionals to developing effective STEM curriculum. Incompatibility of identities is defined as identities that are unable to be merged socially, such as STEM and female identities that hold contrasting social expectations, which can distance one from actively engaging in activities (Archer et al., 2017; Aschbacher et al., 2010).

The stereotype threat for young girls and STEM is especially important to address as stereotypes of STEM that have been perpetuated by the media such as being socially awkward, conventionally unattractive, and unskilled at relationships are perceived as being incompatible with the female gender role, further distancing the two identities from one another (Cheryan et al., 2012, 2011). Stereotype threat and incompatible identities share many similarities as they are both affected by media and culture, but they vary in how they can be addressed. Non-stereotypical role models are more successful in cultivating and inviting women into STEM as they challenge the preconceived stereotype (Dasgupta and Asgari, 2004). In contrast, when role models do encompass some aspects of STEM stereotypes, even if the interaction was positive, women can be drawn away from the field due to stereotype threat (Cheryan et al., 2011). The selection of role models is vitally important when promoting STEM to young girls, especially in education outreach programs.

A lack of programming and support from schools oftentimes leads to the inability of students to develop the necessary identities needed to be successful and persevere in STEM (Archer et al., 2017; Aschbacher et al., 2010). Generally, schools lack sufficient programming which includes qualified teachers and funding for potential STEM candidates to develop STEM identities (Stokes et al., 2017). Middle school teachers tend to be insufficiently qualified and found to lack confidence in their abilities to teach STEM subjects (Du et al., 2019; Ejiwale, 2013; Gardner, 1983; Hammack and Ivey, 2019). In addition, schools lack the necessary resources for teachers to improve their own self efficacy. In an online survey conducted by Hammack and Ivey, elementary teachers were asked about their own perceptions of incorporating STEM into their classroom curriculum, to which many responded positively to the idea but felt they were unable to due to the lack of knowledge, training, and administrative support. Teachers instead have to rely on external training and support to get the resources they needed to develop STEM education lesson plans and to collect necessary technology (Hayden et al., 2011). STEM learning and identity development are therefore typically only able to be enhanced through programming opportunities such as after-school programs (i.e., dedicated clubs), contests and fairs, hands on design and build, and summer programs (Ejiwale, 2013).

Student identity has been shown to be an important factor when determining STEM participation post high school due to its role in shaping motivation, capability, and goals (George, 2000). It is normal for students to participate in a number of different identities, negotiating between each community's identity based on its values (Aschbacher et al., 2010). Archer et al. attributes the incompatibility of STEM and gender identities based on cultural norms as a key barrier to girls participating or "performing" in STEM. For example, multiple studies have shown that girls who placed less value on their gender identity were able to form stronger attachments to their STEM identities (Archer et al., 2017; Aschbacher et al., 2010; Hippel et al., 2015). The use of media, such as the typical representation of a scientist or an engineer as a male, has been seen as a barrier to the development of a STEM identity due to the incompatibility of a "male" profession to women. This has been combated at the National Institute for Women in Trades, Technology and Science (iWiTTS) CalWomenTech Project through the use of recruitment images showing women in these professions, resulting in 15% increase of female students recruited for the computer networking and information technology program at the City College of San Francisco which has been attributed to the change in marketing media (Milgram, 2011).

Numerous formal and informal education programs have been developed to increase girl's interest in STEM through hand-on STEM focused activities, mentoring programs, and role models (Bamberger, 2014; Goodwin et al., 2014; Jayaratne et al., 2003; Knezek and Christensen, 2020; Laursen et al., 2007; Levine et al., 2015; McColgan et al., 2018; Muraleedharan and Valley, 2021; Portsmore et al., 2019; Robson et al., 2020; Steinke et al., 2021; Stoeger et al., 2013). The current literature is well established on the positive impacts that such efforts have on girls' STEM attitudes, as inferred by participation in follow on actions and involvement in STEM activities [42]. Susana Gonzalez-Perez et al. evaluated a role model intervention program where female volunteers who worked in STEM spoke to girls in school from ages 12 - 16 about their careers. Surveys were conducted before and after the sessions to evaluate the program's effectiveness on enjoyment, expectations of success, and aspirations in STEM. On average, the intervention had a significant positive effect and even saw a reduction in gender stereotyping. Programs such as Bring Up Girls in Science (BUGS) have had marked success through mentoring and after school programming with hands-on laboratory work. Through longitudinal analysis of students involved in BUGS from middle school to college compared to control groups showed higher positive perception of STEM (Tyler-Wood et al., 2011). Unfortunately, most of these educational outreaches, specifically informal programs, are short-term and require students to apply for the service which excludes those who have already leaked out of the pipeline with low attitudes on STEM. These hands-on programs and mentorships are not able to reach the students that are most at risk of leaving STEM due to external pressures.

To address the limitations in informal outreach programs, a long-term, continuous mentoring and tutoring program was developed for a local middle school in Denver, Colorado in partnership with the Colorado School of Mines STEM undergraduate and graduate students. The middle school involved is a STEM focused school that is part of Denver Independent School District (DISD) which utilizes open enrollment. This open enrollment is not based on the location of the students but is instead based on parents and guardian preferences, which are then compiled and finalized by the district. All schools in the district are involved in this process. The program included the revamping of a currently operating science club, one-on-one mentoring, science and math tutoring, and the development of mentor-protégé relationships. The program did not require the students to apply for any of the services and provided students access to a diverse group of STEM mentors. The goal of the project was to understand if students' recognition of STEM adults was proportional to their self-identified STEM attitudes in addition to understand student attitudes before and after the introduction of the program. This study is unique to the literature as it actively looks at students who are enrolled in a STEM curriculum that is typically characterized by having more hands-on activities to help connect students closer to STEM. This connection is vital to the development of a STEM identity which is highlighted above, but there still exists a disparity in STEM attitudes between boys and girls, even with the additional STEM connection. Through the mentorship intervention provided from the informal outreach program, STEM attitudes were seen to show improvements in the young girls involved.

Methodology

A long-term informal education program was developed and implemented from spring of 2016 to spring of 2018 at a middle school (6^{th} – 8^{th} grade) in the DISD with Mines. The middle school's population consisted primarily of low-income, non-white students with 95.5% of students classified as non-white and 91% of students receiving free or reduced lunch[1]. The extracurricular program included the creation of a weekly science club and provided mentor support for an existing weekly math and science tutoring program hosted every Tuesday and Thursday. Mentors were STEM college students from Mines who were primarily female. Mentors were solicited through an email database from the university's Society of Women Engineers (SWE) organization.

[1] Children can qualify for free or reduced lunch if their families earn at or below 130% of the federal poverty level or are between 130 – 185% of the federal poverty level (U.S. Department of Agriculture, 2017).

University students who were interested in the position were requested to submit a resume which was followed up by an interview. Those selected for the program were paid a competitive rate to ensure that the students who were hired consistently participated throughout the length of the program. This was to ensure the mentors maintained their mentor-protégé relationship with the same students throughout the lifetime of the program. Training was provided to the mentors on the importance of mentorship and their role in this position. Additional training was provided by teachers regarding specific tutorials to be used for tutoring sessions. On average, 11 undergraduate college mentors participated each semester, with a 75% return rate of participate from one semester to the next (e.g., Spring 2016 to Fall 2017). Attrition was attributed to student graduation or time commitments.

Math and science tutoring was held every Tuesday and Thursday for one hour. College mentors were trained to assist students with math and science homework questions and teach tutorial modules designed by the middle school teachers. Approximately 10 minutes was included in each tutoring session to allow for discussions on STEM careers, activities, and opportunities. Science club was hosted after school in collaboration with middle school science teachers. The main focus of the science club was the design and execution of student science fair projects. College mentors were paired with students to help them with the development, design, and experimentation throughout the semester, resulting in finalized science fair projects for the Denver Metro Regional Science Fair. Projects were selected based on the student's interest. Teachers offered incentives for students to attend tutoring and the science club in the form of extra credit for their classes.

A student attitudes toward STEM (S-STEM) survey was used to evaluate the students' attitudes and role model recognition. The survey was based on the "Upper Elementary School and Middle/High School Student Attitudes toward STEM" survey developed the Friday Institute for Educational Innovation at North Carolina State University (Hayden et al., 2011). This survey is a common tool utilized by similar programs to evaluate intervention programs that focus on improving students' confidence and efficacy in STEM subjects (Faber et al., 2013; Karakaya and Avgın, 2016; Luo et al., 2019; Wilson et al., 2012). The survey was shortened to 48 questions to specifically focus on student recognition of role models through the student's ability to recognize an adult working in these fields and their attitudes towards STEM. The survey was administered by the homeroom teachers during the homeroom period using a secure link to an online survey tool, SurveyMonkey. Proper consent protocols were followed in accordance with institutional review board approval (COMIRB # 16-0963).

The S-STEM survey used Likert questions to assess 21st century, science, engineering, and mathematics attitudes using a five-point scale. 21st-century skills are defined as the ability to think critically, communicate effectively, collaborate with others, and think outside of the box which are skills to be highlighted as being necessary in the future especially in STEM (Han et al., 2021). The Likert questions were phrased as self-assessing for the students to the corresponding attitude like, "I am confident I can lead others to accomplish a goal", "I am good at Math", "Science will be important to me in my life's work", and "I am good at building and fixing things". The responses were "Strongly Disagree," "Disagree," "Neither agree nor disagree," "Agree," and "Strongly Agree." A 1 – 5 point scale was assigned to each of the responses. For role model recognition in students, four additional questions were asked for students to determine if they knew a scientist, engineering, technologist, and/or mathematician. The options available were “Yes,” “No,” and “Not sure.” These values were also assigned numerical values for the analysis. This method allowed for students to self-recognize role models in STEM fields.

A total of 1,100 surveys were collected over the two-year study period. Incomplete surveys, which were surveys that did not complete the Likert attitude and role model recognition questions, were removed from the analysis, leaving a total of 475 surveys to be analyzed further. A total of 400 students, some of whom completed the survey over multiple semesters, submitted completed surveys: 49% were female and 51% were male. Only 24% of students who submitted surveys participated in the program activities.

A total of 37 surveys were collected from students who attended the program over multiple semesters which allowed us to perform a limited longitudinal trend analysis of the data. All students were not able to be tracked over the full two years due to the administration limitation of the survey, which meant only two consecutive semesters (e.g., Fall 2016 - Spring 2017) could be analyzed over time. From the reoccurring sample, 60% of the students were female and only 14% participated in the mentor-mentee, tutoring, and science fair program

For hypothesis testing, the data was separated into specific groupings for mean comparisons. Independent t-test was used for groupings of all students and only girls based on extracurricular participation and attitudes. Chi-squared test was used for the groupings of students and young girls based on extracurricular participation, STEM role model recognition, and grade/future class expectations. Whitney U-test was also used for a similar grouping of chi-squared. The level of significance was set to a value of $\alpha = 0.1$ for all the tests.

Results and Discussion

The baseline S-STEM survey results confirmed the literature about the continued downward trend of attitudes that girls' STEM attitudes follow without interventions. Boys had a mean composite STEM score (average of all four attitudes: 21st century, math, science, and engineering) of 3.78 (n = 204) while girls had a mean of 3.63 (n = 196), showing a difference of 0.15. Figure 2 shows the composite attitudes of the four attitudes tested in the S-STEM survey. There are two interesting observations in this data set. First, math attitudes in Spring 2016 and Spring 2017 revealed that female attitudes are significantly elevated and slightly elevated (more positive) when compared to their male peers. The second observation is the similarities in 21st century attitudes for both male and female students. This attitude stays closely tied to one another as seen in Spring 2016, Fall 2016, and Spring 2018. This could be due to these skills more closely aligning to the female identity of being charismatic, communicative, and collaborative which overcomes two of the primary barriers of stereotype threat and incompatible identities (Brotman and Moore, 2008; Cheryan et al., 2012, 2011).

The boy participants (n = 204) in the survey had continuously higher STEM attitudes than the girl participants. This observation confirms the current literature about boys STEM attitudes generally being more positive than their female peers. Middle school is also around the time where these attitudes begin to differ more dramatically with boys perceiving STEM more positively while girls perceive it more negatively (George, 2000). This could be contributed to the lack of stereotype threat and incompatibility of identities with the more abundance of media with male STEM role models allowing for boys to develop these STEM identities (Cvencek et al., 2011). Boys also typically obtain more attention in the classroom (Levine et al., 2015) and gain/perceive different levels of support from parents (Lee et al., 2020; Shapiro et al., 2015).

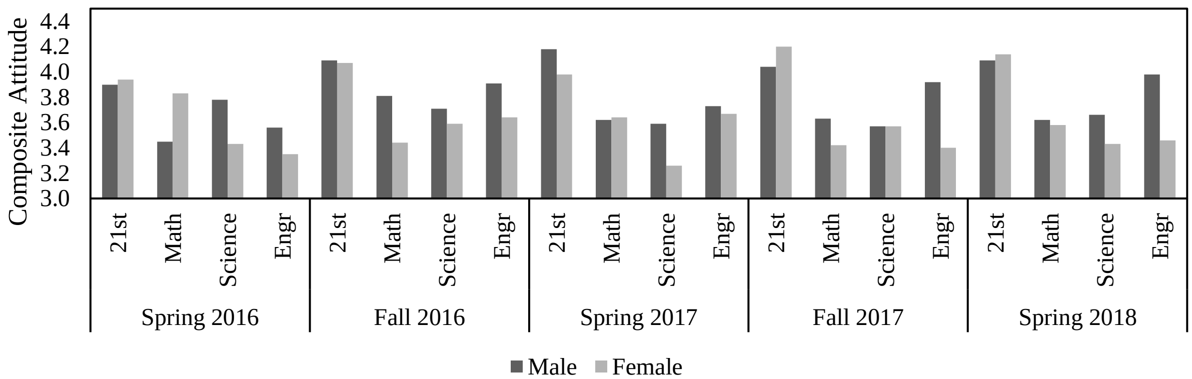

Figure 2: The composite attitudes for each of the semesters that the survey and extracurricular program was in place at the middle school for the 400 surveys. The attitudes were averaged for all female and male students by assigning a 1 – 5 point scale to responses of "Strongly Disagree," "Disagree," "Neither agree nor disagree," "Agree," and "Strongly Agree," respectively.

In general, no statistical significance was found through hypothesis testing when comparing attitudes, role model recognition, and grade expectations in math and science courses. However, for girls who completed the survey over multiple semesters (n = 22), an observed difference could be seen. Figure 3 shows girls that completed the survey over multiple semesters and participated in the extracurricular STEM activities saw an increase in their STEM attitudes when compared to girls who completed the survey over multiple semesters but did not participate. For example, from

Fall 2016 to Spring 2017 an increase of 6.4% to 10.1%, respectively, was observed. Girls who did not participate in the extracurricular activities saw a decrease in attitude which varied from 1.2% to 5.5% decrease. This decrease in composite attitudes supports the general theory that middle school girls who go through school without extracurricular STEM support, such as mentoring or role models, "leak" out of the STEM pipeline. Another interesting observation is girls who did not participate in the extracurriculars had higher overall attitudes when compared to those who did participate in Fall 2016 but had lower overall attitudes in Spring 2017. This could potentially be attributed in some part to the negative stigma that is attached to tutoring programs which tend to target lower-performing students which is enforced by teachers requiring students who are struggling to attend to improve their grade (Robinson et al., 2021). Students who attend tutoring could view themselves as struggling in STEM and feel they are not "smart enough" due to the perpetuating stereotype that smart students do STEM which hinders the development of a STEM identity and reduces STEM attitudes (Aschbacher et al., 2010).

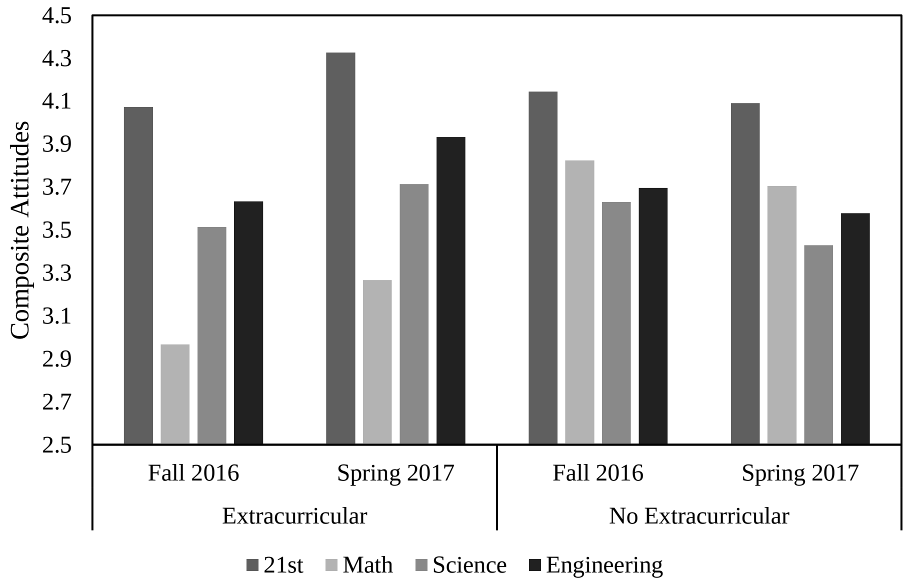

Figure 3: The average STEM attitudes for recurring girls (n = 22) in Fall 2016 and Spring 2017 shows that girls who are involved in the extracurricular activities see a general increase in their attitudes while girls who are not involved see a decrease in their attitudes.

Role model recognition was also reviewed for girls who completed the survey over multiple semesters from Fall 2016 to Spring 2017. Figure 4 shows the composite role model recognition, comparing girls who did and did not participate in the extracurricular program. Both showed increases in their recognition of STEM role models but those who participated in the program saw a 36.7% increase while those who did not participate saw a 17.5% increase. Girls that were active in the extracurricular program had increased recognition and increased attitudes while girls who were not active had some increase in recognition and decreased attitudes. This can be seen in Figure 3 and Figure 4. Research on role models, specifically for promotion of STEM, note that even with the introduction of role models, girl's attitudes can decrease due to the role model's close association with negative stereotypes such as being unskilled in relationships (Cheryan et al., 2012, 2011). This negative perspective by the student could be enhanced by the student's own closeness to their female identity.

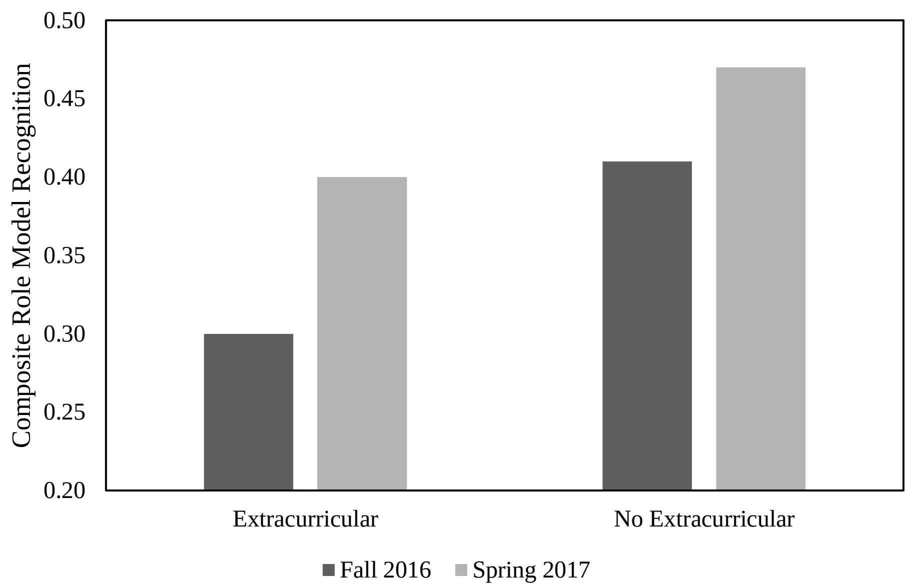

Figure 4: The composite role model recognition for reoccurring girls (n =22) from Fall 2016 to Spring 2017. Responses for role model recognition were originally categorized as "Yes," "Not sure," and "No". These values were converted into a numerical array where 2 = Yes, 1 = Not sure, and 0 = No. Each student had these four values (scientist, technologist, engineer, and mathematician) averaged to create a composite value.

Although the survey results suggest improvement in STEM attitudes and role model recognition for middle school students who participated in the interventions, the analysis of the overall results (n = 400) did not show statistical significance. This could be due to a number of factors. Direct observation of the students suggest that the survey was too long. On average, students took ten minutes to complete the survey, but some students required longer and were therefore unable to complete all of the questions due to time constraints in their homeroom session. Additionally, teachers were asked to take time out of their homeroom session to send out the link to the survey and wait for the students to complete the survey. Depending on the teachers' curriculum, teachers varied in their ability to the administer the survey. This potentially could contribute to the low response rates in Fall 2017 resulting in limited ability to track student responses over multiple semesters. Therefore, recurring student responses were the most prevalent in the two semesters that had the most responses. To address this limitation in the future, a shorter survey is recommended with the use of a sign-in survey which would assign students a unique number for ease of tracking.

Spanish was selected as the preferred language of choice for 16% of the students at the middle school who completed the survey (n = 400). There is some concern that those who did not complete the survey did so because they did not fully understand the survey questions as they were written only in English. Consent forms were provided in both English and Spanish, translation of the survey into Spanish and other commonly-used languages is recommended to reduce future misunderstanding and allow the participants to respond to the questions more easily.

The middle school utilized in this study is a STEM charter school whose students enroll through the district's open enrollment process by the parents. Parents' choice could introduce a positive bias into the STEM attitudes of the students. Interestingly, even though the school was directed towards STEM, young girls continued to underreport their STEM attitudes, have lower role model recognition, and lower grade expectations than their male peers. A comparison of a similar program being initiated at a non-STEM focused school with similar demographics should be conducted to determine if this potential bias could have a played a significant role in the students' responses.

Conclusions

A long-term continuous mentoring and tutoring program was developed for a local middle school in Denver, Colorado in partnership with STEM focused college students to address the attrition of women from STEM careers. The program also addressed limitations from similar studies by increasing the accessibility of the interventions to students who were leaked out or in the process of leaking out of the STEM pipeline. The program included the revamping of a currently operating science club, one-on-one mentoring, science and math tutoring, and the development of mentor-protégé relationships that was observed to benefit not only the middle school students but also the college mentors. The program was unique in that it offered free services without requiring the students to be accepted through an application process, increasing the accessibility of the resources to students, especially those who might have already been leaked out of the STEM pipeline. It also provided students access to a diverse group of primarily STEM female mentors to work with.

To evaluate the effectiveness of the program, an amended S-STEM survey was administrated once a semester for a total of four semesters. The STEM attitudes and role model recognition of the students were evaluated using this survey. There was no statistical significance in the populations of participants in the program and the control group, but there was an observed difference in the female participants and the female control group. The observed results indicate that, even in a STEM-oriented middle school, girls continue to have lower STEM attitudes when compared to their male peers. Girls that participated in the STEM extracurricular program saw a positive increase in their STEM attitudes while those who did not saw a negative decrease over two semesters of surveys. Role model recognition saw a 36.7% increase for female participants while the control group decreased in recognition. The biggest indicator of increasing STEM interest was access to STEM role models either at home or through access from the enrichment programs. Findings from this work confirm that the selection of role models involved in mentoring is vitally important when promoting STEM in education outreach programs. Additional research should be continued in this field focusing on long term monitoring of cohorts to evaluate the effectiveness of similar programs. One major limitation to the study presented in conducting a significant longitudinal study is due to the limitations regarding the administration of surveys to students. Surveys were administered inconsistently by homeroom teachers due to lack of time in the classroom. There are a few ways the data collection process could be improved to address this limitation. First, surveys should be shortened to require only 5 minutes, instead of the 10 – 15 average that was observed. Secondly, the survey tool should require student log in that assigns a random moniker which would help track students who did not put their name or put “playful” names. Finally, additional incentives should be provided to the teachers themselves to administer the survey. Through the inclusion of these practices, the longitudinal study could be more successful and provide statistically significant results.

Appendix A – Amended Friday Institute S-STEM Survey

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1. I am confident I can lead others to accomplish a goal.	○	○	○	○	○
2. I'm confident I can encourage others to do their best.	○	○	○	○	○
3.I am confident I can produce high quality work.	○	○	○	○	○
4. I am confident I can respect the differences of my peers.	○	○	○	○	○
5. I am confident I can help my peers.	○	○	○	○	○
6. I am confident I can include others' perspectives when making decisions.	○	○	○	○	○
7. I am confident I can make changes when things do not go as planned.	○	○	○	○	○
8. I am confident I can set my own learning goals.	○	○	○	○	○
9. I am confident I can manage my time wisely when working on my own.	○	○	○	○	○
10. When I have many assignments, I can choose which ones need to be done first.	○	○	○	○	○
11. I am confident I can work well with students from different backgrounds.	○	○	○	○	○

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
12. I am good at Math	○	○	○	○	○
13. I would consider choosing a career that uses math.	○	○	○	○	○
14. Math is hard for me.	○	○	○	○	○
15. I am the type of student to do well in math.	○	○	○	○	○
16. I can get good grades in math.	○	○	○	○	○
17. Math has been my worst subject.	○	○	○	○	○

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
18. I am sure of myself when I do science.	○	○	○	○	○
19. I would consider a career in science.	○	○	○	○	○
20. I expect to use science when I get out of school.	○	○	○	○	○
21. Knowing science will help me earn a living.	○	○	○	○	○
22. I know I can do well in science.	○	○	○	○	○
23. Science will be important to me in my life's work.	○	○	○	○	○
24. I can handle most subjects well, but I cannot do a good job with science.	○	○	○	○	○

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
25. I like to imagine creating new products.	○	○	○	○	○
26. I am good at building and fixing things.	○	○	○	○	○
27.Designing products or structures will be important for my future work.	○	○	○	○	○
28. I would like to use creativity and innovation in my future work.	○	○	○	○	○
29. Knowing how to use math and science together will allow me to invent useful things.	○	○	○	○	○
30. I believe I can be successful in a career in engineering.	○	○	○	○	○

About Yourself

1. Are you a boy or a girl? BOY GIRL
2. What grade are you in? 6th 7th 8th
3. Which language do you prefer to speak in? English Spanish Other
4. Which math class are you in?
5. How often do you attend math tutoring after school? Weekly 1 time per month Never
6. How often do you attend science tutoring after school? Weekly 1 time per month Never
7. Are you participating in Science Fair?
8. How well do you expect to do this year in your:

	Not Very Well	OK/Pretty Well	Very Well
English/Language Arts Class?	○	○	○
Math Class?	○	○	○
Science Class?	○	○	○

9. In the future, do you plan to take advanced classes in:

	Yes	No	Not Sure
Mathematics?	○	○	○
Science?	○	○	○

10. Do you plan to go to college?
    - ❍ Yes
    - ❍ No
    - ❍ Not Sure

11. More about you.

	Yes	No	Not Sure
Do you know any adults who work as scientists?	○	○	○
Do you know any adults who work as engineers?	○	○	○
Do you know any adults who work as mathematicians?	○	○	○
Do you know any adults who work as technologists?	○	○	○

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CHAPTER THREE: APPLYING PROCEDURAL JUSTICE TO SUSTAINABLE REMEDIATION SOCIAL INDICATORS FOR DEVELOPING COUNTRIES WITH INFORMAL ECONOMIC LIVELIHOODS: A CASE STUDY

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Abstract

In response to traditional remediation criticisms that often fail to consider social and economic factors, sustainable remediation balances environmental, social, and economic considerations during cleanup efforts. Although frameworks are available to apply sustainable remediation principles, they are limited in their application to developing countries and do not reflect the influence of polluting informal economic livelihoods on the project design. In this work, we evaluated the performance of select sustainable remediation social indicators using a case study of Ogoniland in Nigeria, demonstrating the indicators' limitations as applied to a communities dominated by these polluting informal livelihoods. To overcome these limitations, we incorporated principles from three frameworks focused on involving communities in development projects--Socially Responsible Engineering, Engineering for Social Justice, and Responsible Research and Innovation--to better incorporate procedural justice into existing sustainable remediation social indicators. The three frameworks provided the necessary tools to adapt the social sustainable remediation indicator measurements to account for informal economic livelihoods, demonstrating their potential for addressing the shortcomings of current sustainable remediation indicators in developing countries.

Introduction

Developing countries are disproportionally affected by legacy and industrial contamination while also most likely to possess a high population of people participating in polluting informal livelihoods such as artisanal and small-scale mining (ASM), e-waste recycling and chemical manufacturing. Approximately 92% of the 8.3 million pollution-related deaths per year occur in developing countries (GAHP, 2019; Landrigan et al., 2018). However, remediation efforts in developing countries often fall short due to technological barriers, socioeconomic tradeoffs, political instability, poor appropriation of funds, and insufficient capacity for regulation and supervision from government and local institutions (Evans and Kantrowitz, 2002; O'Brien et al., 2021a). Much of the failure has been attributed to a lack of integration of social and environmental considerations throughout a project's life cycle. As such, site remediation efforts require a balance of efficiency, economy, and social awareness to maximize their effectiveness. However, traditional remediation efforts focus heavily on the cost, time, and effectiveness of project implementation, rather than the environmental and social impacts (Braun et al., 2019; Harclerode et al., 2016a; U.S. EPA, 1995) suggesting a disconnect between current implementation and recommended practice.

For the last two decades, researchers have criticized the traditional approach to remediation for failing to properly analyze and incorporate environmental, social, and economic impacts which can occur during and after remediation (Bryant and Wilson, 1998; Lesage et al., 2007; Rizzo et al., 2016). While remediation is perceived to hold a generally positive association with those involved due to cleaning up the environment, the involvement in the decision-making process is often restricted to the most affluent stakeholders or technical experts. Often, disenfranchised and marginalized communities are excluded from the discussions and efforts surrounding the remediation, thus making traditional remediation insufficient in dealing with historical legacies of mistrust and environmental injustices (Beckett and Keeling, 2019; Jardine et al., 2013; Kiessling et al., 2021).

A promising option to overcome the environmental and social disconnect of traditional remediation practice is through the incorporation of sustainable remediation (SR) principles. SR is the practice of considering the effects of implementing an environmental cleanup and incorporating options to minimize the footprint of the cleanup actions (Cundy et al., 2013; Ellis and Hadley, 2009). SR emphasizes a balanced decision-making process across environmental, economic, and social indicators (Braun et al., 2020a; Rizzo et al., 2016). This is done by incorporating sustainability assessments to provide both quantitative and qualitative data to evaluate remediation options, with an emphasis on early intentional stakeholder engagement (Braun et al., 2021; Ellis and Hadley, 2009; Harclerode et al., 2016b). SR provides the basis for potentially situating environmental degradation within local contexts to enable the identification of inequality and disenfranchisement (Beckett and Keeling, 2019). However, the SR approach and principles are traditionally applied to developed countries with little evidence of its effectiveness or applicability to the unique challenges of developing communities.

There has been continued growth in both the adoption and practice of SR in developed countries, especially in the US and the UK, as more organizations continue to develop frameworks and guidance documents that are updated with newer research, especially as it relates to the inclusion of the social dimension in sustainability (Favara et al., 2019; Harclerode et al., 2015; Hou et al., 2016, 2014). Recent developments in these frameworks and documents include new criterion to assess stakeholder involvement in the decision-making process (Bardos, 2014; Braun et al., 2019), but challenges still exist on how to incorporate these (Norrman et al., 2020). Developing countries have not received as much attention in SR as developed countries, both in the academic and practical context (Braun et al., 2020b; Hou et al., 2014). SR remains in the initial adoption phase in developing countries without any significant progress being made due to a shortage in many countries of public policies that support sustainability or integrated approaches to stakeholder involvement as seen in developed countries (Braun et al., 2020b, 2019; Diaz-Sarachaga et al., 2017). Additionally, as the dominant frameworks and guidance documents for SR are based on research and case studies from developed countries (Braun et al., 2020b; Bryant and Wilson, 1998), these frameworks may not accurately reflect the unique challenges for remediation in developing countries (Cao, 2007), such as the prevalence of polluting informal economic livelihoods (e.g., ASM, artisanal refining, battery recycling, and e-waste recycling). The informal sector contributes to almost half of the documented remediation projects in developing countries with many of the projects facing funding barriers due to the informal nature of the activities (O’Brien et al., 2021b) and alienation by both the government and other community members (Luttrell, 2015; Schwartz et al., 2021). Remediation efforts in developing countries that are home to communities characterized by informal economic livelihoods may benefit from a more holistic approach to remediation given that the sectors are deeply rooted in environmental, economic, and social conditions of a site. This raises the question as to how SR can be applied to developing countries with communities characterized by informal economic livelihoods to produce lasting environmental protection.

The purpose of this paper is to adapt the SR social indicators to remediation efforts in developing countries that are home to communities characterized by informal economic livelihoods. Using a case study based in Ogoniland, a region decimated by widespread contamination due to historical oil production and artisanal refining in Nigeria, we highlight the limitations of current SR social indicators, especially as they relate to understanding the influence of the informal economic livelihoods. This is followed by improvements of SR social indicators though applying concepts of procedural justice through frameworks that are focused on the process of community engagement to improve these indicators for future use in communities that are dominated by informal economic livelihoods such as ASM and e-waste recycling. To the authors' knowledge, this study breaks new ground by applying procedural justice to SR social indicators to adapt the indicators to the unique challenge of the presence of environmentally damaging informal economies in developing countries.

The paper is organized as follows: section two synthesizes SR's social indicators and the theory of procedural justice with the three frameworks to be used. Section three presents the methodology used to analyze and apply procedural justice to the case study in the efforts of adapting the existing indicators that are related to informal economic livelihoods. Section four provides background for the case study of Ogoniland and the current efforts of remediation in the region. Section five assesses SR social indicators connected to livelihoods in the Ogoniland remediation work, highlighting their limitations, and applies concepts of procedural justice to address these limitations. Finally, the conclusion points to future research objectives that would continue adapting SR indicators to increase accessibility to developing communities that are reliant on informal economic livelihoods.

1. Synthesizing Sustainable Remediation and Procedural Justice

Sustainable Remediation Social Indicators

Several organizations have published indicators – or characteristics that express a social, economic, and/or environmental aspect – that are used for assessing the sustainability of different environmental remediation processes (Cappuyns, 2016). For a review of such efforts, the reader should look at ASTM, 2013; Ellis & Hadley, 2009; ITRC, 2011; NICOLE, 2012. Because no comprehensive, well-defined, and globally used list of SR indicators exists to describe the assessment of sustainability, we based our assessment on the synthesis of indicators reported by Braun et al., 2021. Braun et al., 2021 analyzed 21 published SR frameworks, selecting a subset of 63 indicators within the SR environmental, social, and economic categories. Of these indicators, 25 are considered social indicators as outlined in Table 1. For more detail on each category, subcategory, and how they were validated by stakeholders, the reader is referred to Braun et al., 2021.

Table 1: Sustainable remediation social indicators and how the indicator can be measured (Braun et. al., 2021).

Indicators	Measurement
1. Respiratory effects	Equivalent mass or PM 2.5 emitted or Comparative Toxicity Unit
2. Other health risks and community safety due to traffic and machine operation	Fatality potential based on distance traveled by off-site transport or intensity; Subjective
3. Occupational hazards of workers due to exposure during remediation processes	Types of exposed risks
4. Risks of accidents and injuries of local workers	Incident or fatality based on hours worked and type of tasks performed
5. Degree of protection offered to workers during remediation processes	Types of protection or security measures provided
6. Employment and income opportunities	Number or percentages of jobs created
7. Equal opportunities	Potential for women's participation in different work compartments
8. Learning/training opportunity, skills development, and education	Subjective
9. Opportunity and strengthening of the local economy and business	Potential for using local sources
10. Interruption, migration, or closure of local businesses	Subjective
11. Community improvements and benefits	Subjective
12. Creation or recovery of green, recreational, and leisure spaces or infrastructures	Subjective
13. Compromise of local tourism and cultural heritage	Subjective
14. Cultural and tourism promotion	Subjective
15. Improvements in the aesthetics of the local environment	Subjective
16. Restoration and suitability of the site for future reuse	Type of reuse
17. Effects of properties neighboring the site	Type of reuse
18. Stakeholder satisfaction and acceptance	Potential for participation and form of engagement of different stakeholder groups
19. Trust and transparent communication	Subjective
20. Ethic of the companies and selection of remediation techniques	Subjective
21. Transferring impacts to future generations	Subjective
22. Robustness, quality, and precision of investigations and evaluations	Subjective
23. Reliability and resilience in the face of changes	Subjective
24. Compliance with local policies	Subjective

As seen in Table 1, the SR social indicators include community and worker health and safety, employment, local economy, quality of life, future site use, stakeholder participation, and social responsibility. As applied to remediation efforts, the goal of analyzing such topics is to provide both quantitative and qualitative assessment into the effect of remediation activities on local and global communities. This work will be focused on the social indicators as they are applied to communities that are dominated by informal economic livelihood activities that generate significant pollution as it is important to address both the issue of contamination in remediation and the reason for the generation of the pollution simultaneously (Schwartz et al., 2021), which would require direct community involvement and participation. Additionally, social considerations are typically the least prioritized in environmental remediation as engineers are more experienced with the technical elements involved in the environmental considerations (Braun et al., 2021; Hou et al., 2014).

Procedural Justice

The existing SR social indicators can be enhanced by integrating principles of environmental justice (EJ), specifically, aspects of procedural justice that the indicators currently do not represent. The principles of EJ describe the way environmental costs and benefits are distributed, how communities are recognized, and the process in which communities are involved in decision making of environmental management (Menton et al., 2020). Distributive justice tends to dominate the literature in EJ about the unequal distribution of pollution (Heydon, 2020; Schlosberg, 2007). Solely focusing on distributive justice, however, fails to address the cause of inequity, which begins first with the fair inclusion of marginalized communities in the process of environmental management (Ikeme, 2003; Schlosberg, 2007). The social indicators for SR currently exemplify the focus on distributive justice by focusing on the outcomes and not on the process. Procedural justice is the fair inclusion of all people in the environmental decision-making process (Schlosberg, 2007). The focus on the process, which procedural justice does, is important to bring about the desired outcomes of sustainability, especially as it is related to the social and environmental issues (Leydens and Lucena, 2018; Lucena et al., 2010).

There are multiple existing frameworks that integrate procedural justice into science and engineering practice. For our analysis, we selected three – Socially Responsible Engineering (SRE), Engineering for Social Justice (E4SJ), and Responsible Research and Innovation (RRI) – to apply procedural justice to existing SR social indicators that are related to the informal economic livelihoods. Each of these frameworks focus on intentional community engagement through understanding structural and power conditions within a community, identifying community's capabilities, and adapting decision-making to the community's needs, desires, and values. To begin, SRE provides a framework to be used to include all stakeholders in a project, especially those who are marginalized, into the decision-making process (Smith and Lucena 2020). Intended as a supplemental framework to the existing engineering code of ethics, SRE specifies the groups of peoples to whom engineers are responsible to and calls on engineers to acknowledge their role in existing power structures. SRE's five criteria can also be utilized as a way to promote procedural justice in environmental decision making: 1) understanding structural conditions and power differentials among stakeholders, 2) contextually listening to all stakeholders, specifically those who are marginalized, to identify a community's needs, desires, capacities, and fears involved in a project, 3) collaboratively identify costs and benefits of an engineering project on all stakeholders, 4) adapting engineering decision-making to promote shared values, and 5) collaboratively assessing activities and outcomes with stakeholders.

Similarly, E4SJ was developed as a guide for engineers to map multiple community perspectives in the process of problem definition and solution to fairly determine the costs and benefits of environmental management decisions (Leydens and Lucena, 2018). E4SJ was developed with social justice in mind, as it aims to enhance human capabilities through equitable distribution of opportunities and resources while reducing the imposed risks among community members. The framework has six key criteria: 1) listening contextually, 2) identifying structural conditions, 3) acknowledging political agency/mobilizing power, 4) increasing opportunities and resources, 5) reducing imposed risks and harms, and 6) enhancing human capabilities.

Finally, RRI aims to encourage the responsible conduct of research and technology deployment by utilizing the four key pillars of anticipation, reflexivity, inclusion, and responsiveness (Stilgoe et al., 2013). These pillars advance procedural justice, as it foregrounds broader ethical reflection through public dialogue (Stilgoe et al., 2013). RRI seeks to understand the intended and potentially unintended impacts that might arise from the implementation of a technology on the economic, social, and environmental experiences of a community; reflect on the underlying purposes, motivations, assumptions, and risks of a potential research project or technology; navigate the complexities of power conditions within local contexts; and respond meaningfully to stakeholders and public values (Di Giulio et al., 2016; Owen et al., 2013). RRI is potentially very useful for developing countries, in that it centers local contexts, cultures and practices, and addresses the power structures of political economy to prevent the perpetuation of neo-colonization (Macnaghten et al., 2014).

Methods

The paper is specifically adapting the SR social indicators to the unique challenges of a community dominated by informal economic livelihoods. Due to this focus, only select indicators that are impacted by these activities were selected. These indicators were related to employment and income opportunities, learning/training opportunities with skills development or education, opportunities to strengthen the local economy and business, stakeholder satisfaction and acceptance, and transparent communication. Table 2 shows how these indicators' measurement was adapted to be more applicable to remediation efforts in a developing community that is reliant on polluting informal economic livelihoods, such as the case study of Ogoniland, Nigeria. These measurements were adapted utilizing the principles from the three frameworks presented above.

Table 2: Amended SR social indicators that are impacted by polluting informal economic livelihoods.

Indicators	**Measurement**
Employment and Income Opportunities	Community input on job interest, availability, and longevity
Learning/Training Opportunity, Skills Development, and Education	Community buy-in on the interest of trainings and education, their capabilities to utilize these trainings, and the resources to carry out their newly found knowledge
Opportunity and Strengthening of the Local Economy and Business	Community interest as entrepreneurs or laborers for remediation efforts
Stakeholder Satisfaction and Acceptance	Development of conflict management, assess community's satisfaction and acceptance of decisions
Trust and Transparent Communication	Identify community needs, desires, expectations, and capacities

We chose the case study of Ogoniland due to the availability of data that was publicly available regarding the remediation process and its subsequent progress throughout the years. There are numerous publicly available documents and reports from third-party organizations such as the United Nations Environmental Programme (UNEP), Amnesty International, Social Action, Stakeholder Democracy Network (SDN), and the Centre for Environment, Human Rights and Development (CEHRD), as well as activity reports from the Hydrocarbon Pollution Restoration Project (HYPREP), the federal organization in Nigeria responsible for the remediation in Ogoniland. These documents provided site assessments, stakeholder questionnaire assessments, community testimonials, remedial action assessments, and general updates of remedial action over the years. Complicated remediation projects with multiple actors may not be characterized by standardized reporting requirements, hence the importance of selecting a project that had an ample amount of documentation to reflect multiple perspectives.

Documentation was collected by an Internet search for the keywords of "Ogoniland remediation report", "Ogoniland cleanup report", and "Ogoniland HYPREP report". From this original search, the reports from UNEP, Amnesty International, Social Action, SDN and CEHRD, and HYPREP's were collected. In total, we found 22 publicly available reports to be used for content analysis. HYPREP produced 82% of the found documents. The analysis of the reports was based on 1) an investigation of the content of each report and 2) the relevance of the content to the selected indicators. It is important to note that our assessment of the indicators as they are applied to the case study is not an assessment of the remediation actions made by the contractors or the Nigerian government. Our assessment is focused on the indicators' ability to assess the sustainability of the remediation activities and the adaption of them using procedural justice principles.

The reports, when combined with the SR social indicators highlighted in Table 2, allowed us to identify limitations of these indicators to assess the sustainability of remediation efforts in developing countries that are home to communities characterized by polluting informal livelihoods. Three key limitations were determined: 1) employment opportunities, 2) livelihood training quality and usability, and 3) meaningful community engagement. Many of these limitations were addressed by these indicators at a surface level but were unsuccessful in assessing the long-term sustainability or resiliency of these remediation efforts.

Case Study: Remediation Efforts in Ogoniland

Ogoniland is a resource-rich region in Nigeria that is located in the southeast of the Niger Delta. Ogoniland's history in the last 70 years has been fraught with human rights violations, environmental injustices, and political corruption that has led to the current mass hydrocarbon contamination of soil, groundwater, surface water, and degraded environment of the once-thriving communities and ecosystems (Amnesty International et al., 2020; EarthRights International, 2014; Giadom and Wills, 2021; Kashi, 2008; UNEP, 2011). Complicating matters in the remediation efforts is the strong presence of artisanal refining, an informal economic livelihood. Artisanal refining involves the processing of illegally tapped crude oil in simplified stills to boil the crude oil (Onuh et al., 2021). The refined oil is then used locally for lighting, energy, or transport. Unfortunately, this process has little regulation or safeguards for the environment which include the clearance of valuable coastal vegetation, contamination of soil and groundwater with crude oil, and air pollution. Through the mistreatment by both the Nigerian government and the extractive transnational companies that have operated in the region since the 1950s, the disempowerment, marginalization, alienation, and deprivation of natural resources and well-being of the Ogoni people have led to the general mistrust and apathy toward future progress of remediation (Giadom and Wills, 2021; Joachim, 2018; Kashi, 2008; Nwozor, 2020).

The initial site assessment conducted by the UNEP identified 69 sites that needed cleanup which HYPREP, the Nigerian agency tasked with remediation activities, divided into three categories: complex, less complex, and further investigation required (Amnesty International et al., 2020; UNEP, 2011). As of April 2022, HYPREP has focused on the less complex sites, which have been separated into two batches for Phase 1 of their implementation of remedial action. Local contractors bidded on these sites and have been working on them since 2019. Batch 1 has 17 out of 21 sites and Batch 2 has 2 out of 29 sites that have been completed and certified with the National Oil Spill Detection and Response Agency (NOSDRA), with 18 additional sites waiting to commence the certification process (HYPREP, 2022a). HYPREP has begun to make plans to expand its remediation program to include more complex sites and conduct new site assessments for newly contaminated sites in Ogoniland that the UNEP report does not have listed, which are due in part to continued artisanal refining activities in the region (HYPREP, 2022a, 2022b).

In addition to the remediation work conducted by local contractors, HYPREP has focused on the creation of employment opportunities to reduce the need of artisanal refining by promoting contractors to hire local youths to construct biocells for the remediation, resulting in the creation of over 1,000 temporary jobs. Unfortunately, due to the delay in funds by HYPREP, many of these jobs were not continuous and were limited to the timeframe in which the contractors physically worked on site. HYPREP has also developed livelihood trainings for women and youths to promote agricultural business and production with fish, chicken, farming, and cassava processing for more long-term employment opportunities. These programs have not had long-term success due the livelihood program's focus on training and not on creating wide-reaching economic opportunities. Many of the women involved returned to their previous forms of employment due to the failure of the cooperatives developed under the trainings. HYPREP continues their work in Ogoniland and appears to be learning from their mistakes, highlighting the need for meaningful community engagement in their latest activities report and the inclusion of ex-artisanal refiners in the creation of new livelihood trainings.

Analysis

The analysis is split into two separate sections. The first section is the initial assessment that explains the ways in which the case study of the remediation efforts in Ogoniland have failed to properly include the Ogoni people into the process of decision-making, resulting in limited success of their remediation objectives developed by the UNEP. These limitations are summarized in Table 3. The second section is the proposed adaptation to the indicators utilizing procedural justice principles from the three frameworks of SRE, E4SJ, and RRI. It also includes examples from the remediation efforts in Ogoniland on how to adapt current efforts to better apply procedural justice principles for the inclusion of marginalized voices into the environmental decision-making process.

Table 3: Summary of initial assessment of SR indicators using the remediation efforts of Ogoniland

Indicators	**Limitations**
Employment and Income Opportunities	Failure to account for long-term employment opportunities to prevent the growth of artisanal refining after remediation efforts are completed. Community members are concerned about how people were selected for the jobs as it was not discussed within the community.
Learning/Training Opportunity, Skills Development, and Education	Trainings were not successful long-term as the kits provided did not account for the resources that the women had available to them.
Opportunity and Strengthening of the Local Economy and Business	The cooperatives developed for women to become entrepreneurs through the trainings were not successful and did not deliver upon the women's expectations.
Stakeholder Satisfaction and Acceptance	Many of the communities in Ogoniland are not satisfied by the efforts of HYPREP due to lack of participation and conflict management between them and the hired contractors.
Trust and Transparent Communication	The dissemination of communication between HYPREP, CRAC, and the community is failing. This has resulted in missed opportunities for many of the community members such as medical outreach and alternative livelihood training.

Initial Assessment of Sustainable Remediation Social Indicators

SR indicators currently assess employment and income opportunities through the number or percentage of jobs created, but do not differentiate between short- and long-term employment, which can have a significant impact on the local economy (Gill et al., 2016). In the case of Ogoniland, the UNEP recommended the Nigerian government provide additional employment opportunities in Ogoniland to prevent the growth of artisanal refining, which is a major barrier to the success of remedial efforts (UNEP, 2011). HYPREP attempted to address these issues of unemployment by hiring local contractors, who employ an average of 20 youths per community with over 1,000 youths employed throughout the life of this project (SDN and CEHRD, 2021). These youths were nominated by the community itself, but there is limited information about this nomination process, with some community members voicing concerns about the selection process. However, SR social indicators are not granular enough to account for the seasonal shifting of employment that can occur based on the availability of the jobs. Nor do they take into consideration the capacity-building that these employment opportunities could have to develop skills for future jobd. Furthermore, while remediation is not occurring or while there is a pause in the disbursement of funds, many of those who were employed will either return to their previous positions or find new positions in the informal livelihood. This was seen in Ogoniland with limited or short-term employment from HYPREP, which also saw delays for multiple months in payment (HYPREP, 2021a, 2021b, 2021c, 2021d), and thus further undermining the remediation efforts. This example illustrates how the failure to account for long-term job growth can ultimately reduce the ability of this SR indicator to assess the social sustainability of remediation projects. Communities could provide valuable input both into the type of jobs that they are interested in performing for the remediation and the type of jobs they would be interested long-term, building in training for these positions into the short-term job.

SR indicators currently assess learning/training opportunities, skill development, and education, focusing on opportunities to strengthen the local economy and businesses. Despite this, SR indicators fail to provide an adequate measurement of the quality of these programs or initiatives. For example, HYPREP has made additional efforts to increase and diversify employment opportunities through the creation of cooperatives and alternative livelihood training. A total of 400 women were trained in agriculture business to create 20 cooperatives with very limited success. Training included agriculture, chicken husbandry, and fish farming. Many of the cooperatives ultimately failed, as cited by the women involved, due to inadequate starter packs and unfulfilled expectations (SDN and CEHRD, 2021; Social Action, 2022). HYPREP does have plans to expand this livelihood training to about 3,000 young people based on various skills but has recognized the need to incorporate a needs assessment to better fulfill the desire and capacity of the involved communities for these initiatives to have better long-term success (HYPREP, 2021e; SDN and CEHRD, 2021). Although the Ogoniland case study does account for livelihood training and thus fulfills the requirements of this SR indicator, the resulting project calls for consideration of the longevity of success that would be required of these programs to phase out the informal employment of artisanal refining. One way this could have done is through a public dialogue with those interested in the training program, discussing their capabilities, their availability of resources such as materials and space, and their interests as emerging entrepreneurs in their communities.

Finally, SR indicators prioritize trustworthy and transparent communication, which is measured through the potential for participation in various forms with different stakeholder groups. Unfortunately, this measurement fails to assess the quality and level of engagement that would be required of communities to identify needs, desires, expectations, and capacities which would also contribute to the identification of sustainable alternative livelihoods, identification of marginalized community members, and assess the community benefit to the available resources. In Ogoniland, community engagement is lacking (Amnesty International et al., 2020), and HYPREP has made note of this in its latest activities report (HYPREP, 2022a). SDN and CEHRD, a third-party organization tasked with overviewing HYPREP's progress, surveyed 1,400 community members across 14 communities with active remediation to assess community awareness and satisfaction with the clean-up. Almost 80% of the communities were under a 3.5 satisfaction score on a Likert scale (1 = complete dissatisfaction, 5 = complete satisfaction), with community participation and conflict management being the major reasons of concern. Additionally, in the same survey, communities at almost 40% of the cleanup sites felt that their complaints were not being resolved or heard by the contractors or HYPREP. Issues of conflict with contractors, community members, and HYPREP were attempted to be addressed through the establishment of six Central Representative and Advisory Committees (CRACs) but has been ultimately unsuccessful due to the lack of dissemination about these resources. When resources are offered, such as medical outreach or livelihood training, communication is limited with many community members either not being informed about it or being informed too late (Social Action, 2022). Although fulfilling the obligation of community engagement by speaking to local government area (LGAs) chiefs by requesting land or resources to be used, the projects has had no obligation to ensure that the project is appropriately responding to specific community priorities or concerns. Community engagement can be difficult in diverse communities, but it is extremely valuable to connect the community with the project and those involved to work through issues of conflict, decision-making, and to disseminate information, such as the availability of CRAC, medical outreach, and other trainings or workshops.

Overall, the biggest limitation to the SR's social indicators as it relates to the informal livelihoods in developing countries is the lack of acknowledgement or measurement of procedural justice. The focus of the indicators is based on the distribution of the costs and benefits related to remedial action, such as the improvement to the aesthetics or community improvement/benefit from remediation. This closely aligns with distributive justice, which is important but not sufficient. Procedural justice is an important element of EJ that should be considered early on in projects since it is based on the process in which decision are made. Ogoniland highlights these limitations of failing to incorporate the community into the decision-making process, especially as it relates to the informal livelihoods. Ultimately, the failure of properly understanding procedural justice has caused additional delays to the remediation process or even caused additional barriers to the development of trust between the communities of Ogoniland with the Nigerian government.

Proposed Indicators Utilizing Procedural Justice

The three frameworks – SRE, E4SJ, and RRI – explicitly and implicitly emphasizes the importance of contextual listening with their specific criterion and dimensions. The community must be properly engaged to practice contextual listening, which can be assessed by the participation and engagement of different stakeholders, the identification of values and expectations of the community, the understanding of power dynamics with special attention made for marginalized communities, and finally, the availability of stakeholder assessments at all phases of the remediation process. Contextual listening can be defined as a multidimensional listening process in which the listener acquires meaning and understanding from a speaker in the context of the world surrounding the speaker, such as history, political agenda, desires, capacities, etc. (Lucena et al., 2010). While this paper has focused on specific indicators related to employment and alternative livelihood training due to their importance of addressing informal livelihoods, all the social indicators would benefit from the inclusion of contextual listening to determine the community's expectations and goals within the scope of remediation. Contextual listening is important to procedural justice as it addresses biases of knowledge (scientific vs. local) and power, while fostering a bottom-up approach to problem definition and solutions, and integrates stakeholder perspectives (Lucena et al., 2010).

HYPREP's community engagement activities in Ogoniland have been limited in the past few years to speaking with local chiefs of the LGAs to discuss land allocation of HYPREP activities such as water stations and the CRACs representatives, who are intended to act as intermediaries between the community and HYPREP. Unfortunately, these representatives have been unsuccessful in reaching out to the community with 33% of the communities that are actively being remediated being unaware of them. The communities in Ogoniland have begun to voice their frustrations to HYPREP about the lack of inclusion and participation in decision-making, specifically requesting for a Project Mentoring Committee to be established to assess the quality and pace of work of the contractors on the remediation projects. HYPREP has begun to recognize the importance of community input for their livelihood training initiatives, issuing over 5,000 Needs Assessments to develop an understanding of the youth's, women's', and men's' skill sets in 2021. Additional assessments were distributed in 2022, targeting artisanal refiners. Currently, the data from these assessments are being analyzed to provide input to the design and implementation of new programs in Ogoniland. Communities are viewed homogenously in Ogoniland, with little to no representation by actual community members in HYPREP or CRAC. Opinions are determined through questionnaires and assessments, not through contextual listening within the context of the community itself.

SR indicators currently assess the creation of jobs but fail to specify the long-term impact of these positions and whether they strengthen the economy, increase community capacity, and reduce the reliance on informal economies. Ideally, the jobs created should account for the interest of the community based on their desires and values, as identified through intentional community engagement opportunities (Brown and Westaway, 2011; Hanh, 2021). To better evaluate whether projects are improving short- and long-term employment, the SR indicator related to employment and income opportunities should be modified to encompass community buy-in for alternative livelihoods. Engineers should use a combination of qualitative and quantitative measurements for evaluating this SR indicator, such as the results of community surveys and workshops as well as the number of short- and long-term jobs created. In communities with informal sectors, such as Ogoniland, contextual listening can provide valuable information on the scale of the sector, the knowledge and skillsets of the artisanal refiners, and barriers to entry into pre-existing employment opportunities. SRE and E4SJ are helpful as frameworks to be utilized to enable these engagement processes to provide an environment to properly conduct contextual listening, opening the space to those who are typically not heard or recognized. These frameworks require the engineers to recognize their role of power they hold as assumed knowers of knowledge and flips this power back to the people. This transfer of power allows for the flow of new knowledge based in the local context to inform designs, decisions, and implementation of remedial actions, both technical and social. Additionally, RRI provides additional follow-up of care to assist in the building or rebuilding of trust between those in the position of authority and the community by providing the appropriate level of responsiveness and reflection. In Ogoniland, CRAC could be utilized to provide a public forum for community members to discuss remedial actions, trainings, and employment opportunities. This would require CRAC to become more transparent with increased dissemination of information. Through this existing organization, community members and HYPREP officials can meet and discuss the existing employment opportunities, improvements to be made, and ways forward for future opportunities.

A common methodology used to diminish the reliance of informal activities in developing countries is the deployment of alternative livelihood training initiative. SR indicators currently assess both the learning/training opportunities, skill development, and education and the strengthening of the local economy but fails to assess the long-term success of these initiatives. Ideally, these capacity-building projects should create employment opportunities by building on community desires, capabilities, and values into marketable careers. To better characterize the success of training initiatives and capacity building, the SR indicator related to learning/training opportunities should be measured based on the needs, capacity, and desires of the community being identified related to these activities and the percentage of successful training outcomes based on stakeholder assessments. Similarly, the impact on the local economy and businesses should be measured based on the different types of employment opportunities created for local communities that are not dependent on remedial action. Contextual listening remains a valuable tool to be used to understand the skillsets and interests that the community has in training opportunities to develop their own entrepreneurial businesses as their own form of employment. These trainings can be used as a form of capacity-building for the community to overcome the barriers of entry to formal employment that are identified through contextual listening. When addressing the concerns of informal activity, such as artisanal refining in the case of Ogoniland, these trainings should target the informal workers in initial engagement outreaches, understanding their interests, their motivations, and their skillsets that they can transfer. Together, trainings can be developed and implemented with better chances of success as they are built around the targeted community within their context. SRE, E4SJ, and RRI highlights the importance of proper inclusion with stakeholders, not just those who have significant power or decision-making, but those who have historically been left out as well. In Ogoniland, current efforts are being made to bring current and ex-artisanal refiners' inputs into the design of future trainings through questionnaires, but additional efforts could be made to have an increased platform of influence through public dialogue, especially since artisanal refining continues to grow in the region, with increased ties to the communities.

Procedural justice grounded in these frameworks – SRE, E4SJ, and RRI, move to asset-based community development. Asset-based community development is a strategy to promote community-driven development that allows communities to organize, implement, and respond to community identified concerns (Mathie and Cunningham, 2005, 2003). Community engagement is key to understanding the local context of defining problems and their solutions, developing expectations and goals to be reached based on the dialogue of the community. SRE, E4SJ, and RRI place dialogue with community members at the center of their frameworks, centering marginalized members in the discussion. SRE and E4SJ place special attention on identifying a community's unique capabilities, disrupting the typical deficit-model mindset that perpetuates development projects in developing countries. RRI focuses specifically on understanding community's vulnerabilities, both seen and unseen, to lead to better decisions and ultimately a better society to address issues of maldistribution. With the incorporation of stakeholders, purposefully targeting members of communities that were historically left out or unrecognized into the decision-making process, these frameworks work together to prevent the inequitable distribution of costs and benefits.

Conclusion

SR has had limited adoption and practice in developing countries due to existing frameworks and guidance documents failing to account for the close connection between remediation and the polluting informal livelihoods that many developing communities are reliant on for employment. Due to the illegal nature of many of these informal activities, community members that participate in these activities are widely alienated or disempowered by the government or by fellow community members, preventing access to resources to assist in preventing and/or cleaning up contamination. SR indicators, specifically the social indicators, need to be adapted to be more appropriate for these communities, focusing on addressing both the contamination and the informal sector simultaneously as they are closely connected to one another.

The case study of Ogoniland highlights the close connection of informal livelihoods to remediation and the barriers it has to the success of remedial action. Additionally, it highlights some key limitations of SR social indicators that relate to employment and the lack procedural justice. The limitations were focused on the employment opportunities available to the communities as this is a major driver for the growth of informal livelihoods such ASM, artisanal refining, and informal battery recycling. In the case of Ogoniland, fair inclusion of communities in the decision-making process was severely missing in the SR social indicators, especially in the way that these indicators were measured or assessed. These limitations were able to be addressed utilizing SRE, E4SJ, and RRI frameworks that could be utilized to include procedural justice into the measurement of these indicators.

Future work in SR and its application in developing countries should include a more robust and holistic analysis of all the SR indicators using all the principles of EJ such as distributive justice, recognitional justice, procedural justice, and capabilities. Additional frameworks could be utilized to assess each of these justice principles, expanding upon the indicators discussed in this paper as the original focus was on the indicators related to informal livelihoods. SR remains a promising approach to handling contamination in developing countries, but currently fails to properly accommodate for the interconnected informal sector that needs to be addressed in parallel with the contamination of communities in these countries.

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CHAPTER FOUR: CONCLUSIONS AND OPPORTUNITIES FOR FUTURE RESEARCH

Engineers are known for their technical skills which are ingrained in them through their education in post-secondary schooling, primarily utilizing EPS to define and solve problems. Unfortunately, modern day engineering education, which has been strongly influenced by Cold War scientification, is not reflecting the necessary changes that are required of modern-day engineers that have been highlighted by the National Academy of Engineering. The Academy highlighted typical attributes of engineers such as strong analytical skills, inventive, creative, communicative, but also be knowledgeable in humanities and social sciences. These necessary changes to the engineering curriculum include the integration of sociotechnical design in either existing required coursework, such as in Capstone projects or Senior Design, or the creation of new coursework for engineers to take that explore the connection between engineers and communities. The lack of change in the education structure can be potentially linked to act as a barrier to the recruitment and retention of underrepresented groups in engineering as it remains highly technical, undermining the values of social knowledge. Due to this lack of change and undermining of these values, those who were successfully recruited struggle with their sense of belonging and their identity as an engineer, losing those who were interested in directly working to achieve societal good through their work.

This thesis demonstrated that middle school girls saw improvements in their STEM attitudes by participating in an informal education outreach program that partnered college STEM mentors with middle school mentees. Through these types of programs, engineering stereotypes can begin to be challenged with the assistance of engineers by showing these students how engineering can directly help their community. One example of this could be a science club project that builds solar powered charging stations for the homeless in the community. Through these types of projects, both social and technical thinking can be introduced, challenging the typical technocentric stereotype of engineers, while also introducing students to engineering as a profession.

Once these students are recruited, they can then be retained in engineering through the integration of socially and environmental just principles in sustainable remediation, such as in Chapter 3. Many underrepresented students who are interested in engineering and studying in post-secondary institutions have been shown in the limited literature to have a larger interest in being a socially responsible engineer and being motivated by values of helping their community. Unfortunately, engineering has remained significantly technical, even with the current push for increased stakeholder involvement in the framing, design, and decision-making process. This topic was explored by examining the integration of social indicators and procedural justice to better incorporate marginalized community members in the decision-making process. Even when using a framework that has been developed by engineers that have pushed for sustainability and resiliency in remediation projects, it could be seen that engineering was still lacking a significant portion of the social element. Going forward, it highlights the need for engineering education to balance the value placed on social science knowledge and the technical knowledge that is taught in engineering education.

There is currently very little literature linking the recruitment and retention of underrepresented groups and integration of social considerations as a barrier in engineering. This thesis begins to provide some foundation for future work to be conducted to change the dominant image of engineering as being technocentric, potentially aiding in recruiting and retaining these underrepresented students. There are some challenges though that can arise from this challenge, specifically with the undermining of knowledge valuation where those who are socially aware, or conscious being seen as not being engineers in the work environment and even the research environment. This is why challenging the technocentric or masculine characteristics of engineering as a whole is important for long-term success of recruiting and more importantly retaining a underrepresented groups in engineering.

Future research may include analyzing the effect of different engineering mentors on STEM attitudes or interest in STEM in students. For example, analysis could be done to see if having mentors who more frequently work in the sociotechnical sphere of engineering, such as BME, environmental engineering, humanitarian engineering, has a greater impact on STEM attitudes. This analysis could also be done on race of both the students and college mentors, as there is little research regarding the influence of socially conscious change and people of color when it comes to future professions. Additional research could also be conducted in a site remediation course where students can be asked to conduct a small-scale remediation project using either traditional remediation principles or sustainable remediation principles with their reasoning. Analysis could be conducted on their response to why they selected one over the other.

Engineers have had a lot of attention placed on them in the last two decades to increase the diversity and inclusivity of the profession, as that will be required as the demand for engineers continues to grow. An interdisciplinary group of engineers with diverse perspectives will be able to provide solutions to the global problems that we currently face today.

APPENDIX A – AUTHOR CONSENT FORMS

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Co-Author Name: Kathleen M. Smits

Title(s) of Co-Authored Work(s):

Promoting STEM Interest in Middle School
Girls Through Strategic Engagement with College Student Mentors
Applying Procedural Justice to Sustainable Remediation
Social Indicators for Developing Countries with
Informal Economic Livelihoods: A Case Study

Co-Author Statement of Consent:

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