ENABLING UNTRAINED TEACHERS TO BE ENGINEERING FACILITATORS: A DESIGN-BASED RESEARCH STUDY OF TEACHER PROFESSIONAL DEVELOPMENT IN FRAGILE CONTEXTS

by

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For my daughter, Aarudra, and for all the women who made me the person I am today.

This dissertation is dedicated to all the teachers who inspire students like me.

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ABSTRACT

Estimates of "Street Youth" (SY) (those who live/work on the streets) show 150 million around the world, with approximately 50,000 in Kenya alone as of 2018. Challenges these youth face remain a significant barrier to national governments achieving Sustainable Development Goal 4 (Quality Education) targets, as formal schools limit access or fail to provide meaningful and supported learning experiences for SY. However, informal learning spaces that empower youth to solve problems themselves may provide them with the knowledge and skills they are denied by formal schools. SY rescue, rehabilitation, and reintegration centers all around the world emphasize and place education at the center of their operations. Recommendations for educational services for SY include providing flexible, alternative education and skills training for youth unable or unwilling to return to school. However, the lack of skilled professionals working with the SY population is one of the most critical challenges.

To meet the learning needs of vast numbers of SY, teachers already connected to this population must be trained in teaching more empowering, skill-based courses such as engineering, which are typically complex. Such innovative, problem-centered curricula demand skilled teachers who are prepared to facilitate a more student-centered classroom. However, sub-Saharan Africa faces a shortage of 17 million formally qualified teachers, even for its formal public schools. Therefore, connecting with the teachers in the context and training them in engineering teaching is crucial. Researchers have long argued the need for teacher professional development to be continuous and long-term. Through this dissertation, I present a Design-Based Research (DBR) study of untrained Teacher Professional Development (TPD) in collaboration with three aspiring engineering teachers at an alternative school for SY in western Kenya. I draw on the theoretical framework of Situated Learning and Communities of Practice (CoP) to discuss the outcomes of a three-phase professional development program. Each phase was designed using the recommendation from McKenney et al. (2006) to include three iterative micro-cycles of analysis, design, and evaluation leading to a meso-cycle. In total, three meso-cycles were completed to arrive at DBR's final phase of reflection and generation of design principles.

In the first phase, teachers in this study adopted reflective practice strategies to increase their awareness of the practice. Analysis from the study showed that the teachers individually and

collectively showed resilience to challenging and complex experiences by establishing a strong foundation for the community of practice. In the second phase, teachers engaged in action research to improve both teaching and learning outcomes. Results demonstrated increased active participation of the teachers in their teaching practice, and developed new understandings of engineering teaching. However, the first two studies also showed the challenges limiting the teachers from constructing an engineering teacher identity and unresolved questions about the sustainability of the TPD. Therefore, in the last phase, the teachers adopted mentoring new teachers as a strategy to develop their identities and sustain the engineering TPD.

The findings from the three phases resulted in generation of design outcomes that include a situated understanding of the theory in this fragile context and design principles that are transferable in comparable settings. Implications of this work suggest a sustainable teacher professional development model for untrained engineering teachers in fragile contexts and present relevant design principles for the CoP.

OUTLINE OF THE DISSERTATION

In this dissertation, I discuss my research in five chapters. In the first chapter, I use the Design-Based Research framework to show the basis of my research. I describe the motivation behind this research, literature review, theoretical framework, overall research methodology, and introduction to the three meso-cycles of DBR applied in this research. The research methodology sets the foundation for the next three chapters. My work presented in this dissertation started in 2015, and the efforts since then have contributed towards this thesis. Therefore, I offer a detailed description of the context, the participants, and the steps taken in the evolution of this research through a timeline of events.

Chapter 2 presents the first meso-cycle in the DBR, which was completed in April 2018. The chapter presents each micro-cycle of DBR in the first meso-cycle. In this study I investigated the role of reflective practice in the knowledge, skills, and attitudes development of the teachers using a situated learning framework. The research paper was presented and received feedback at an international conference (Action Research Network of the Americas, 2018). The research paper is submitted to the *Journal of Reflective Practice* and awaiting review. The research article is co-authored by my dissertation chair and a committee member.

Chapter 3 of the dissertation research presents the second meso-cycle in the DBR, which was completed in December 2019. The chapter presents each micro-cycle of DBR in the second meso-cycle. Action research, in this study, enhanced the impact of reflective practice by providing pathways for teachers to apply their increased awareness of their practice into action through evidence-based decision making. The research article was presented as a work-in-progress study and received feedback at an international conference (Research in Engineering Education Symposium, 2019). The paper is co-authored by all the teacher participants in the research, the director of the partner institution, and my committee chair. This is the first significant outcome towards integrating the teachers as closer collaborators with our academic research group. The research article is prepared for submission to the *Educational Action Research* journal.

Chapter 4 presents the third and final meso-cycle in this DBR study, which was completed in February 2019. The chapter presents each micro-cycle of DBR in the third meso-cycle. The chapter presents the teachers taking up the task of mentorship to welcome and mentor four new

teachers on reflective practice, action research, and engineering teaching within the engineering CoP. Mentorship evolved as the next cycle intervention to improve the outcomes of the full participation of the teachers in the CoP and to address the sustainability of the TPD. The research article is co-authored by the teachers and the committee chair. The research article is being prepared for submission to the *Journal of Mentoring and Coaching in Education*.

Chapter 5 discusses the contributions from the full design-based research process. The two main contributions from this DBR are the fundamental understanding of the CoP framework in the context and the design principles generated from the intervention that addressed the educational problem of untrained teachers' TPD. The chapter is being considered for publication upon identifying an appropriate outlet.

Collectively, the five chapters address broader research questions and contribute to the field of engineering education teacher professional development, through the generated design principles of training untrained K-12 teachers in fragile contexts.

1. DESIGN BASED UNTRAINED TEACHERS ENGINEERING PROFESSIONAL DEVELOPMENT

1.1 Introduction

It was a typical Monday morning at the Tumaini Innovation Center, located 5 miles from the Eldoret city center in Western Kenya. The (former street) boys were rushing out of the dormitory in their new uniforms to the assembly area at 8:00 A.M. The caretaker and two of the boys were tying the Kenyan national flag to the ropes at the flagpole. The Director, the Program Coordinator, the head teacher, the matron, the social worker, and the volunteer staff at the center lined up in front of the student assembly area. Waiting for the morning activities to start, I stood at one end of the line inquiring with hand gestures how they were doing that morning as the boys joined the others in the area. Some winked; some showed a thumbs up; some nodded their heads like they were asking a question, and in Kenyan style, it meant "all is well!"

Once ready, the caretaker kick-started the assembly. One of the boys stepped forward for delivering the prayer, followed by hoisting of the flag, and then a few more prayer songs, this time accompanied with dance. The morning turned out to be an eventful and energetic one, with smiles of enjoyment all around.

The caretaker then announces that it was time for a recap of the past week, as was done in every formal Monday morning assembly, and a call for any issues that needed addressing. The vibrant atmosphere at the center suddenly went silent. All the boys uniformly kept their faces down, staring at the ground, and purposefully avoiding eye contact. The Director spoke to break the silence. He stated in Kiswahili: "(translated) I heard from the caretaker and matron, some of you were fighting with them and acting rough during the weekend. Now is your time to speak up. Bring the issue to the table". The boys remained quiet. Some of the staff encourage the boys to speak up. After a few more seconds of silence, one of the boys said, "The food menu has remained the same for months, and it is not eatable anymore." Once he finished, one of the staff members responded, "You all need to be happy with what you got. You have a uniform now, and you are looking nice. You have a better life here than the street you were before." One of the boys interrupted suddenly with a loud and stern voice, "Because we don't live in the streets anymore, shouldn't we ask for better?" Everyone was silent again.

Later in the day, the director and I sat in his office, checking in with each other. The director reiterated the question from the morning, asking, "Are we doing everything, for the boys to be better, whether primary school or rehabilitation or engineering?"

In this dissertation, I engage in an effort not only to be sufficient in their learning but to truly make engineering learning better for the youth studying at Tumaini. In striving for novel, research-informed level of engineering teaching and learning for and with these students, I detail the design and inquiry behind a capacity building program for untrained teachers who are facilitating a localized engineering program at an alternative school called Tumaini Innovation Center, in Western Kenya. I use design-based research and work with three teachers to collaboratively design the training program and evaluate it to generate a long-term, continuous, professional development model.

1.2 Statement of the Problem

Multiple inequalities in the forms of gender, class, ethnicity, and regional context are prevalent across education systems internationally (Watkins, 2000). Street Youth (SY) are marginalized across a number of these dimensions, and obstacles to educational access are common. The term "street children/youth" refers to children/youth who work and/or sleep on the streets, whether because of poverty, hunger, being orphaned, or other vulnerabilities (UNICEF, 1994). SY are typically grouped into two broad categories. Those who stay on the street during the day for work and return to a home with a parent or guardian at night are called "children on the street," and those who live in the street during both day and night are called "children of the street" (UNICEF, 2001). SY are a fluid and difficult-to-track population whose fundamental rights to food, shelter, education, and health are frequently violated, resulting in significant health and social risks (Radhakrishnan, DeBoer, & Kimani, 2020a).

Studies on SY have resulted in recommendations for educational, economic, and psychological support as sustainable solutions (Glauser, 2015; Scanlon, Tomkins, Lynch, & Scanlon, 1998; Aptekar, 1994; Ennew, 2003). SY rescue, rehabilitation, and reintegration centers all around the world emphasize and place education at the center of their operations (Ennew & Swart-kruger, 2003). To achieve this objective, the educational context must consider available resources and existing social, political, and cultural structures (Choi & Hannafin, 1995). The design of productive educational environments requires curriculum developers to capitalize on

what is known about how people learn (Berryman, 1991). Although this is a useful general framework, there is little literature informing the design of educational environments specifically for street youth. According to Dewey (1938), the purpose of education is to build the capacity of youth to become successful in life. To become successful, these children deserve more than primary education. While literacy and numeracy skills will prepare them for a potential livelihood, education that enhances their inherent resourcefulness will increase their capacity to have economic freedom through entrepreneurship, access healthier livelihood opportunities through marketable skills, and be self-reliant. The new competency-based curriculum of Kenya, is designed specifically to cultivate students' critical thinking, problem-solving, vocational, and interpersonal skills (Kenyan Institute of Curriculum Development, 2017).

Engineering is distinctively situated as a field of knowledge and practice that cultivates a multitude of skills needed for the social world. Engineering promotes problem-solving, extending the knowledge of design process beyond technical and technological realms. Engineering develops self-agency and empowers individuals to navigate in a three-dimensional world (Miaoulis, 2010).

1.2.1 Engineering for Street Youth in K-12 Classrooms

SY are difficult to support in traditional formal schools due to transience and stigma, and they face enormous challenges in developing the 21stcentury skills needed to enter the workforce. However, informal learning spaces that empower youth to solve problems themselves may provide them with the knowledge and skills that they are shut out from in formal schools. Engineering is uniquely positioned to aid in the development of employable skills. Miaoulis (2010) argued for integrating engineering into the K-12 curriculum, justifying this position by noting that the current science curriculum in the United States covers less than 5% of our day-to-day activities, ignoring the other 95% of the human-made world (mainly focusing on technology). Though the author's justification is based on the United States curriculum, the reasoning on the relevance of engineering in K-12 is recognized around the world including Kenya (Kenyan Institute of Curriculum Development, 2017). According to Miaoulis (2010), "engineering promotes problem-solving and project-based learning, makes mathematics and science relevant to students, offers a wide range of high-paying career choices, and helps all students better navigate a three-dimensional world." (p. 21). Other arguments for the integration of engineering into K-12 settings have related engineers' focus on providing real-world context to learning math and science,

developing problem-solving skills, promoting the development of communication skills and teamwork, fostering fun and hands-on settings, and most importantly, preparing youth for 21stcentury problems and more authentic STEM contexts (Moore et al., 2014).

In the context of our study, Kenya is facing an employment crisis due to the mismatch between workforce demands and education (Wasunna, 2018). The need for qualified technical workers is in high demand, with expanding industrialization and new employment opportunities. Kenya's recent curriculum reform calls for building seven core competencies in K-12 learners: communication and collaboration, self-efficacy, critical thinking and problem-solving, creativity and imagination, citizenship, digital literacy, and learning to learn (Kenyan Institute of Curriculum Development, 2017). Research suggests that engineering learning builds most of these seven core competencies in K-12 learners (Masek & Yamin, 2011). Therefore, we have pioneered an approach to unlocking street youth students' capacity to engineer at an alternative residential school called Tumaini Innovation Center in western Kenya. Our work at Tumaini since 2015 showed that engineering catalyzes SY agency, and that the students identify their teachers to play a significant role in their success (Radhakrishnan, DeBoer, & Kimani, 2018). However, for the teachers engineering was both complex and challenging.

1.3 Terminologies

Fragile contexts: World Vision defines fragile contexts as those "where the government cannot, or will not, fulfill its responsibilities to protect and fulfill the rights of the population, particularly the poor" (World Vision International, 2011). Street youth are a population whose fundamental rights, such as healthcare, education, safety, are often neglected by the government and are deemed a pandemic problem around the world (Shorter & Onyancha, 1999). Therefore, the population itself qualifies as a fragile context. In my research, I adopt the definition of fragile contexts also to qualify street youth supporting centers due to the minimal support provided by the government for the population of street youth and their associated institutions. In addition, the center under investigation qualifies as fragile due to the uncertainty of its economic and programmatic models, where in large part, they depend on external donor and expert support respectively.

Street Youth: "Street Youth" are not a clearly identifiable or homogenous population, but a socially constructed label used to describe "young people for whom the street plays a central role

to live or work" (United Nations, n.d, p.1). In an international, grassroots context, there is a need to differentiate between youth who appear on the streets during the day and those who live on the streets. Those who work on the streets but return to their families at night are referred to as "on the street," while children who are working and living without formal shelter or the presence of parents/guardians are called "of the street" (Glauser, 1997). In the United States, researchers and lawmakers focus only on youth who would be considered "of the street," but they are referred to as homeless/unaccompanied youth (Murphy & Tobin, 2012). Children who are homeless but not in the company of a parent or guardian are considered to be unaccompanied youth. Unlike children who are homeless with their families, unaccompanied youth are those who have left home (runaways), often as a result of physical or sexual abuse or irreconcilable differences with parents, or been told to leave (so-called "throwaways"), either for financial reasons or because parents do not want them at home (frequently because an adolescent identifies as LGBTQ or becomes pregnant).

Teacher Professional Development: "Teacher Development is the professional growth a teacher achieves as a result of gaining increased experience and examining his or her teaching systematically" (Glatthorn, 1995, p. 412). Therefore, Teacher Professional Development (TPD) is a long-term process that includes regular opportunities and experiences planned systematically to promote growth and development in the profession (Cochran-Smith & Lytle, 1999).

Untrained Teachers: Untrained teachers are individuals with no or limited qualification and training in the practice of teaching who are appointed on official capacity as teachers or volunteering teachers by the government, organizations, and institutions to teach students on assigned subjects in an educational environment (Kunje & Stuart, 1999)

1.4 Context

1.4.1 SY and SY Service Providers in Kenya and in Eldoret

In Eldoret, the city where Tumaini is located, various interventions to support SY have existed, with very few sustaining for more than five years to actually provide long-term support to the youth (Ayuku, 2004). In 2013, Onwong'a (2015a) investigated the effectiveness of street children interventions in Eldoret. Since 2003, the national government attempted to address the plight of SY, but most of the developed policies ended up being ineffective at the implementation

level. NGOs were identified as the most active stakeholders in addressing the issue of SY. The author synthesized existing literature and demonstrated that most intervention programs for SY fail as a result of not considering the children's rights, personal needs, and freedom of choice in the provision of services and addressing the symptoms rather than the causal factors (for example, taking the youth back to formal school due to missing school years, without understanding the stigma and other challenges they face in a formal school environment (Radhakrishnan et al., 2020a). The study also identified that the SY in Eldoret do not trust many of the interventions available to them, claiming the intentions of the programs or stakeholders offering the programs to be "selfish"; indeed, most programmatic responses were short-term and were mainly charity-based. Onwong'a (2015a) presented that amongst all the interventions available for SY in Eldoret, 63% of them provided charitable support through resources such as food, clothing, and residential space, 17% of the interventions focused on medical assistance (physical health and counseling) on a needs basis, and 9.4% offered recreational activities such as sports training. Only 13.6% of interventions focused on education as the core service. The author also highlighted the lack of capacity and technical expertise to support the health and educational needs of SY as a crucial challenge faced by SY service providers.

These tendencies of existing programs in Eldoret and Kenya more broadly in fact run counter to what SY point out as needs and aspirations. Based on recommendations from varied research and its own research-based evaluations, Tumaini over the past 10 years has developed into a multi-service institution covering wide range of programs including rehabilitation, reintegration with families, education, job placement, and livelihood support.

1.4.2 Tumaini Innovation Center

Tumaini Innovation Center, an alternative residential school, started as a drop-in center for Street Youth (SY) in the community of Eldoret town, a fast-growing industrial city. There are an estimated 50,000 SY in Kenya (Appendix. A – the recent census data from 2018) and 2500 in Eldoret (Kipyegon, Nyachwaya, & Okirigiti, 2015; Street Families Rehabilitation Trust Fund, 2020). The Tumaini ("hope" in Kiswahili) drop-in center hosted educational and social work activities, including the reintegration of the children with their families and short learning activities. 80% of the children and youth integrated into schools returned to the streets (Radhakrishnan et al., 2020a). The founders of Tumaini learned that schools and families were the primary factors that

pushed SY to the streets in the first place. So, the drop-in center was replaced by a small-scale, focused educational center called Tumaini Innovation Center (TIC) in 2015 with 11 youth (Figure 1). The TIC model was devised through a participatory design approach with the youth and with the motivation to provide a sustainable longer-term intervention that would assist the youth with a career. The center has since operated as a school that offers primary and vocational education content. The subjects covered in primary include English, KiSwahili, Science, Mathematics, Social Science, and Religion. The vocational school offers Motor Vehicle Mechanics (MVM), Welding, Electrical Wiring, and Hair Dressing. The students range in age from 11-18 years in primary and between 14-28 years in the vocational school. The center receives funding from private donors and international and national grants. The school supplements primary and vocational education with skill development programs such as engineering.

Figure 1. The first batch of SY (who came to be known as “Pioneers”) admitted at Tumaini Innovation Center in 2015 wearing their Obama T-Shirts to convey the message of hope

The engineering program started in 2015, with a beta-test in 2016. In April 2018, the students at TIC completed the first module, culminating in the design and installation of a solar

photovoltaic system to light the school's classrooms (Figure 2). In the second module completed on December 2019, the students addressed multiple issues and tested prototypes for each project: a solar refrigerator (addressing fish storage in local lake regions), briquette press (charcoal production as cooking fuel, Figure 3), solar alarm system (security automation in local communities), and improvements to a mechanized farm vehicle.

Figure 2. Engineering students from first LED course preparing for installation of solar PV system to solve the lighting issue at Tumaini

Figure 3. Engineering students from second LED course demonstrating the charcoal briquette press prototype to the user during the Engineering Expo event at Tumaini on Dec. 2019

1.5 Localized Engineering in Displacement (LED)

Our lab's (DeBoer Lab) student-led, integrated LED curriculum uses problem-based learning to teach engineering design, STEM fundamentals, evidence-based decision making, entrepreneurship, and professional skills (communication and teamwork). The class centers around an authentic local challenge (Figure 4). I have been involved in the design of the community-centered engineering curriculum since its beginning in 2015. The engineering curriculum is situated around three areas: (i) Engineering Design Process (EDP), a design-thinking approach for problem-solving, (ii) Technical content, STEM fundamentals necessary to design solutions based on identified problems, and (iii) Professional skills, competencies to build inter and intra-personal skills of the learners. As a community-centered problem-solving curriculum, the engineering design process is the main content area and the connecting thread for all the other content. The engineering design process is integrated with the technical content (such as

electronics like Arduino, sensors, 3D-modelling, automotive mechanics) and professional competencies (teamwork, communication, interpersonal skills) content to help learners improve their solutions using both fundamental and advanced STEM knowledge. The curriculum is built using an Active, Blended, Collaborative, and Democratic (ABCD) framework (Freitas, Beyer, Al Yagoub, & DeBoer, 2018; Radhakrishnan & DeBoer, 2016). The curriculum uses active learning (Felder & Brent, 2009) techniques such as hands-on activities and problem-solving tasks, blended learning (Means, Toyama, Murphy, & Baki, 2013) tools like the tablet and laptop technology with both online and face-to-face modes, and collaborative learning (Dillenbourg, 1999) via team-based activities. Democratic learning, which is grounded in critical pedagogy (Freire, 1968), positions teachers and students to exercise their roles as critical agents of change in society (Freitas et al., 2018).

The term Localized Engineering in Displacement came to be with the adaptation of our model for fostering students' agency to create solutions for themselves in two different contexts (DeBoer, Radhakrishnan, & Freitas, forthcoming). First, it was developed and piloted with the internally displaced SY of Kenya at the Tumaini Innovation Center and second, it was transferred and contextualized the program for the externally displaced refugee population in Azraq refugee camp, Jordan and Kakuma refugee camp, Kenya. The design and implementation of the engineering education model were synthesized based on the curriculum evaluation and outcomes from both contexts, which was then termed Localized Engineering in Displacement (LED).

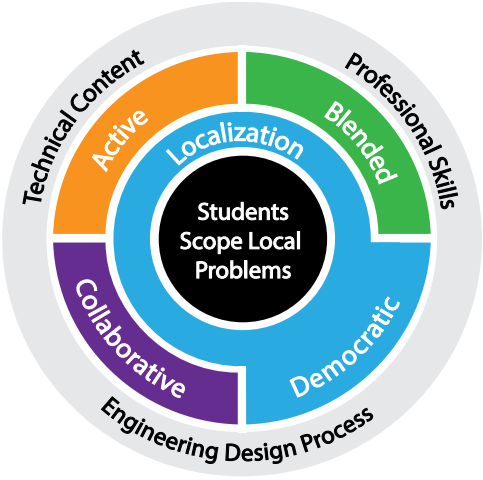

Figure 4. LED Curriculum Approach
(DeBoer et al., forthcoming)

The LED model is built using an asset-based framework, through which the curriculum engages the learners and teachers at the local contexts to build on their existing knowledge of their community and environment, resilience, self-esteem, and social cohesion (McCay et al., 2010). The students identify the engineering needs in their community and, after studying our digital resources and hands-on activities, create their solution (see Appendix C). The asset-based framework focuses on the capacities, skills, and social resources of people and their communities (Mathie & Cunningham, 2005). The framework, an alternative to the deficit-based models, is to think about the potential and about the ways the existing potential can be directed towards available opportunities (Ebersohn & Mbetse, 2003). The approach suggests outside resources can be effectively leveraged by mobilizing its own resources without ignoring the contextual constraints on communities. (Ebersöhn & Eloff, 2006). The asset-based approach concentrates first of all on the agenda building and the problem-solving capacities of the local members and local communities. Our localized engineering program was developed as a result of the collaboration with the Tumaini Innovation Center since 2015 based on the learners' request for a comprehensive skill-development education that could prepare them for the 21st-century workforce. The curriculum, a product of a long-term relationship with the community, aimed at building the problem-solving capacity of the learners, teachers, and the local community members. Ebersöhn and Eloff (2006) reviewed several articles from the Southern African Development Community (SADC) region that presented successful and sustainable education practices and programs accommodation vulnerable children. The authors determined common denominators across programs as indicators of sustainability and grouped the common factors to form an asset-based framework. The authors identified seven key trends to be the common characteristics of asset-based programs that we use in order to explain how our program was built on asset-based framework (Table 1).

Table 1. LED program efforts that met the Asset-based framework

Asset-based trends	**Descriptors**	**LED program efforts**
Community-based participation	Decentralized power — leadership in communities and schools	Aligning with the Tumaini philosophy of the participatory design approach, the engineering program re-centered the power of learners by co-creating the learning objectives.

Table 1. Continued

	Eco-systemic perspective	The engineering design process content as the foundation of the curriculum allowed learners to identify problems and areas of interest to them.
	Relationships instead of reason and rationality	By collaborating with the Tumaini administration outside of the localized engineering curriculum such as fundraising, program coordination, teaching and learning support for primary and vocation schools, leveraging resources for travel between the partner sites, a long-term relationship is established.
	Collaboration instead of fragmented services	Co-participating in training programs such as social entrepreneurship to identify potential pathways for Tumaini and the learners enabled mutual learning and collaboration.
Building and strengthening internal capacities	Collect data about assets, capacities, and resources instead of problems and disabilities	Identifying available contextual resources through weekly meetings and finding strengths of learners and teachers through individualized interaction and formative assessments resulted in relevant solutions.
	Focus on assets and capacities	Teacher development for Tumaini teachers on face-to-face components of the class, additional advanced skills such as reflective practice, action research, and mentorship ensured the sustainability of the engineering facilitation on the ground.
	Professionals are supportive instead of paternalistic	Forming a community of practice and critical friendship where teachers and researchers supported each other without judgments.
Community resource mobilization	Community members are change agents	Students became change agents in the local community through demonstration of engineering skillsets (e.g., solar technicians) to address community issues (e.g., solar alarm systems); Outside community members integration is not well-formed yet.
	Cycle of empowerment instead of dependence	Engineering solutions became products for social entrepreneurship start-ups, with the hope of self-sustaining activities of the organization and the individual
Networking and establishing links	Cross-sectoral collaboration Connects individuals to resources as service delivery	Created and facilitated partnerships for the center with the local university to identify relevant higher education pathways for learners, international NGO's, government and private donors

Table 1. Continued

Advocacy	Creating public awareness	Published research studies demonstrating SY strengths
	Rights approach	Online publications (medium) advocating for SY rights (Radhakrishnan et al., 2020a; Radhakrishnan, DeBoer, & Kimani, 2020b)
	Openness, disclosure, and acceptance	Localized engineering as a cornerstone program was used for the recruitment of vulnerable community youth to participate in education and open the center for the public.
	Holistic understanding instead of labeling and stigmatization	Participated in outreach activities of Tumaini, meeting with other SY in the town to develop concrete understanding of the population
Use locally embedded (indigenous) beliefs, structures, knowledge and practices	Beliefs, systems, and practices of communities and individuals are affirmed	Integration of formal school curriculum contents to make their learning in engineering relevant
	Communities and individuals are viewed as experts, not clients	Acquired culturally relevant content from both teachers and students during the design of the course
	Individuals are seen as having essential viewpoints instead of being ignorant	Enabled teachers through reflective practice strategies to integrate contextual and cultural knowledge in their teaching
Information sharing	Move away from "expert" knowledge towards shared knowledge	Community of Practice as established model as a result of this dissertation research that enabled shared knowledge and development.
	Connecting instead of informing	

Our prior research has shown that co-designing an engineering course with students and teachers can catalyze learner engagement, meaning, and agency and lead to sophisticated engineering products (Radhakrishnan & DeBoer, 2016). The SY learners find the ABCD framework to be motivating and meeting their educational needs

Additionally, our work also showed that students identify their teachers as role models who play a critical role in the success of each student (Radhakrishnan et al., 2018). However, the challenges identified included the teachers' struggle to understand and internalize a challenging

and complex curriculum with many moving parts and in an advanced topic like engineering. The teachers who understand the complex needs of SY, however, lack formal training in STEM education and, for some, formal qualifications in primary school teaching.

1.6 Untrained Teachers and Engineering Teacher Professional Development

Untrained teachers are defined as practicing teachers who have had limited or no training and experience relevant to teaching or the subject being taught, and they are a growing phenomenon in developing countries. They are recruited both to meet the ever-expanding educational needs of the nation and because they need work (Kunje & Stuart, 1999). Primary schools in sub-Saharan Africa employ an average of 36.3% untrained teachers (UIS, 2017) to meet the growing number of students in school through free primary education programs. Adding to this challenge, the teachers handle larger-sized classes and are often tasked with multi-grade teaching; multi-grade teaching is when teachers have students from multiple grades in the same classroom (UNESCO, 2012). Therefore, informal spaces are highly likely to employ untrained teachers and require in-service, informal teacher professional development programs to teach effectively.

Research on teacher development in engineering is not new and has increased in number in the past two decades, mainly through the establishment of the field of engineering education. However, engineering teaching in K-12 spaces is limited, and its research has mostly been situated in the contexts of high-income countries. Engineering education is not typical in informal spaces, for displaced populations, and in contexts of fragility. Therefore, researching the development of teachers in a fragile context opens the door to understand and transfer such programs around the world to similar settings. Literature in Teacher Professional Development (TPD) shows that a long-term process that includes regular opportunities and experiences planned systematically to promote growth and development in the profession is the most effective (Akyeampong, Pryor, Westbrook, & Lussier, 2011; Cochran-Smith & Zeichner, 2009; Hynes & Dos Santos, 2007; Nadelson et al., 2013; Zarske, Yowell, Sullivan, & Carlson, 2004). Therefore, we are faced with the educational problem of *how can we design a long-term TPD that supports untrained teachers to teach engineering while capitalizing on the available assets and overcoming the barriers of fragility?* With this as the driving question, I discuss in the following sections and chapters the design-based research approach applied to a three-phase teacher professional development

program and present the results of the untrained teachers' development of knowledge and skills in a fragile context.

1.7 Evolution of My Design-Based Research

Design-Based Research (DBR) scholars argue that close collaboration with researchers and defined participants is essential to identify and scope a problem and design responsive interventions (McKenney & Reeves, 2018). From the beginning of the project in the DeBoer Lab, we have aligned our efforts to co-create with our collaborator, Tumaini Innovation Center. My efforts in this DBR study also involved close collaboration on defining the problem with the participants. However, since the participants lacked experience in designing interventions, whenever necessary, I, as a researcher, led the efforts in collaboration with the participants and senior researchers involved in the project. In order to clearly express the role played by different actors and how this DBR was shaped, I document the collaborative consultations with other researchers and my research participants that led to the design of this investigation through a timeline of events.

1. In 2016, while continuing the implementation of our engineering course, the first appointed teacher for an engineering course at Tumaini dropped out (three months into the pilot). Tumaini, in the beginning, was highly fragile, as most of the staff and teachers were volunteers. The uncertainties raised the need for having more than one teacher to implement the program. The social worker at Tumaini, William, was initially serving as the second teacher. During one of our weekly check-in Skype sessions, I collaborated with the social worker and the head teacher to identify solutions.
2. As the head teacher and the social worker demonstrated interest in participating in the program, they also identified and brought in the program coordinator at the center to join the team. Over the next three weeks, together, we brainstormed plans and ideas for continuing the implementation. During the weekly calls, they began discussing challenges in handling the course. Initial discussions led to understanding the major problem concerning handling technology, understanding content, using appropriate teaching techniques, and managing the students.
3. In 2017, as I began to identify ways of supporting the teachers, I participated in a one-day working retreat with Dr. Tamara Moore, Professor, School of Engineering Education,

Purdue University (also part of my thesis committee). Her research group during the retreat developed instructional support materials for their EngrTEAMS project. The events of the retreat and conversations with Dr. Moore helped me identify ways to design an instructional manual. I further developed short instructional materials for each class. However, the experience clarified for me the prerequisites needed for the teachers to be able to interpret and follow the manual, such as knowledge and awareness of their students, pedagogical knowledge, and self-awareness of their role as teachers teaching engineering.

4. In the fall of 2017, I qualitatively investigated the part played by technology in changing the role of teachers, due to the predominance of technology and its role in our engineering course. The study gave insights into the importance of teachers in the classroom, as students identified them as role models, and the teachers reported higher self-efficacy while using technology (Radhakrishnan et al., 2018). The teachers also mentioned confusion and difficulty in understanding the engineering design process and explaining it to the students.
5. During November 2017, I conducted a one-week, in-person, professional development session on the engineering design process, whereby teachers identified a problem in their community and worked as a team to design solutions using the design process. This PD session reported satisfaction by the teachers in clarifying the challenges with the design process. However, the teachers continued to express concerns over limited exposure to the technical content in engineering and difficulties understanding teaching methods for the content.
6. During the spring of 2018, as I undertook the course "Action Research in Science Classrooms" with Dr. Brenda Capobianco, Professor, School of Education, Purdue University (also part of my thesis committee), the concerns expressed by teachers led me to understand the need for a longer-term teacher professional development. As I undertook the activities for the class and wrote a starting point speech (Radhakrishnan, Assignment 2, EDCI567, 2018), I identified the gaps in the teachers' qualifications that would be required for teaching the engineering curriculum.
7. Through literature and from the materials and experiences shared by Dr. Capobianco, I identified reflective practice as a strategy for the teacher professional development program. I shared the concept of reflective practice with the teachers and received their thoughts on their interest to participate in learning it. I consulted Dr. Berger to understand his

involvement with establishing and facilitating the Community of Practice and learned the process and benefits of a CoP. In consultation with Dr. Capobianco, and the teachers themselves, we (the three teachers and I) established a professional development group by formulating a central theme, setting expectations and guidelines, and identifying preferred modes of communications and associated structures for the CoP.

8. The reflective practice strategies became the first phase of the design intervention, resulting in a qualitative investigation and a conference publication. I presented the study at the Action Research Network of Americas (ARNA) annual conference and networked with scholars in the field of teacher development using action research. Dr. Margaret Riel (Director, Center for Collaborative Action Research, Pepperdine University) discussed with me the role action research can play in my teacher development program to develop the teachers from reflective practitioners into inquiry-based teachers and shared a multitude of resource materials to design the intervention.
9. I, upon discussion with the teachers, found this as a close complement and a successor to the reflective practice intervention because the first emergent results of the qualitative study revealed the establishment of a foundation for teachers' knowledge and skills to be the three components of CoP: Practice (Teaching), Community (Teamwork), and Domain (Engineering). Also, the teachers provided insights during the CoP meetings on their interest to improve their practice and acquire new skills that have the potential to help their career. Therefore, action research became the second phase while continuing the strategies learned from reflective practice. The video materials (Riel, n.d.) shared by Dr. Riel impressed the teachers and kindled their interest to conduct action research.
10. During fall 2018, I continued to consult with the teachers and discussed strategies for implementation of action research in their classrooms. I visited Tumaini in November 2018 and organized short introduction sessions on conducting action research. We dedicated most of the time to understanding the motivation of each teacher to do research, and we explored interest areas. We began to hone the research questions. During the same week, each teacher also identified specific topic areas such as teamwork, community integration, and the background of street youth at Tumaini and conducted a 45-minute training session.
11. In January 2019, Tumaini expanded with 15 more students and started a vocational school. They are further currently pursuing a plan to increase the strength to 100 more students.

This increase meant more students undertaking the engineering course, and therefore, Tumaini required more engineering teachers. This led to expanding the CoP from four members to eight, with four vocational teachers joining. Additionally, the results from the action research phase revealed the continuing challenges of being accepted as an engineering teacher within and outside Tumaini and of continuing the efforts of the TPD without failure. In consultation with the three teachers, we decided that the three teachers would act as mentors to the newcomers. This expansion is in line with the theory of CoP that posits the sustainability of a CoP depends on the welcoming of newcomers as the old members become mature practitioners (Lave & Wenger, 1991). The mentorship phase still on-going helped teachers to develop a strong identity as engineering teachers through consistent interactions with people outside the CoP and with the newcomers. Mentorship primarily served as a validation of their knowledge, skills, and attitudes as engineering teachers.

12. During the fall of 2019, Dr. Jennifer DeBoer, Associate Professor, School of Engineering Education, Purdue University (also the chair of my thesis committee), and I pursued the idea of registering the teacher professional development curriculum with the Purdue Digital Education program. Upon successful submission, we converted the professional development into a certification program that allowed teachers to receive the certificate and transfer credits from Purdue by completing each phase. In Dec. 2019, we organized an engineering expo event that showcased the LED program innovations developed by the students to the outside community and acknowledged the three teachers with their first certification on reflective practice teaching. We are in the process of evaluating the other two phases and processing the certifications on action research and mentorship. The certification has now ultimately become a design outcome that has influenced the practice of engineering teaching.

1.8 Research Question

One of the most common criticisms of design-based research studies has been around the framing of the research question. Studies that have investigated the process of the research in all the four phases (analysis, design, evaluation, reflection) of DBR have been criticized for having overlooked the main educational problem (McKenney & Reeves, 2013). DBR scholars strongly

emphasize that the research investigation should be addressing the issue that originated the inquiry in the first place. In line with the explanatory nature of DBR, driving questions should, therefore, be open in nature. I benefit from the comments of Edelson (2006) on the assumptions of DBR, pointing out that it begins with the underlying premise that existing practices are inadequate or can, at least, be improved upon so that new methods are necessary. Given the problem that has driven this investigation has been the lack of knowledge and skills to teach engineering in fragile contexts effectively, and sustain such programs, I ask:

How do untrained engineering teachers for SY develop knowledge, skills, and attitudes about the practice of teaching, teamwork with the community of peers, and the domain of engineering?

I refer to the examples and guidance on design and evaluation of professional development by Loucks-Horsley, Stiles, Mundry, and Hewson, (2009) and Guskey, (2000) and propose that investigating the processes that played a role in teacher's development will result in guidelines that prepare untrained teachers as engineering facilitators. Through the design-based research and asset-based framework (Ebersöhn & Eloff, 2006) guidelines to closely collaborate with the participants as equal stakeholders during the entire process, I was able to develop insights on the available assets and contextual limitations and utilize the understandings to take suitable design actions. Through these steps, I address the critiques of the design-based scholars and do not overlook the main educational problem.

1.9 Literature Review

1.9.1 Engineering Teachers' Professional Development

Several studies of engineering education in the K-12 space in the United States have identified related challenges with respect to teacher preparation, including a lack of engineering concepts in teacher preparation programs, attitudinal biases, the existing structure of the K-12 curriculum, the complexity of the content area, limited real-world problem-solving experiences, and a lack of pedagogical content knowledge (Hynes & Dos Santos, 2007; Nadelson et al., 2013; H.-H. Wang, Moore, Roehrig, & Park, 2011; Zarske et al., 2004). Therefore, professional development for teachers in engineering is required to address these challenges and improve teachers' confidence in their ability to implement an engineering curriculum (Jonassen, Strobel, & Lee, 2006).

At Tumaini, realizing the need for teacher capacity development in engineering, training sessions involving teachers in the engineering design process were organized to improve their content knowledge. The teacher training needed to be continuous (see, for example, Jovanova-Mitkovska, 2010) to ensure the sustainable development of pedagogy, content, and technological knowledge and use in classrooms. Identifying the need for and effectiveness of a continuous professional development model was the first step that motivated me to conduct this research investigation. In order to align the research efforts with the cultural and contextual practices, it was important to develop insight into teacher education and teacher professional development in Sub-Saharan Africa (SSA) and, mainly, in Kenya.

1.9.2 Teacher Education in Kenya

Transfer of American education practices that are proven successful such as student-centric classrooms, active learning, and effective integration of ICT cannot be immediately transferred to SSA. Researchers argued the need for concrete understanding of the assets, indigenous knowledge, cultural practices, and specific needs before translating proven best practices from other countries (Johnson, Hodges, & Monk, 2000). Therefore, researchers and program designers need to be aware of the teacher preparation program models and professional development practices in the context of the operation. In the following sections, I further discuss the teacher education models, professional development practices, and research that has informed successes and gaps in sub-Saharan Africa and Kenya to provide a detailed contextual and cultural perspective.

Teacher education programs in Kenya are divided into five types. They are early childhood development and education, primary teacher education, secondary teacher education, technical teacher education, and special needs teacher education (Katitia, 2015). Based on the type of teacher education programs, the curriculum and requirements for graduation vary. For example, for primary teacher education programs, the teaching practice is split into three sessions during their term of three years for about two weeks each session. Whereas, for secondary teacher education, it is three months straight during one semester. Criticisms around teacher education in Kenya have been mostly on the limited amount of time allowed for teaching practice with the majority time focusing on course work (Katitia, 2015). Skills and strategies do not transfer well when they are not learned in situated contexts (Brown, Collins, & Duguid, 1989).

Reports have been published with recommendations for reform of teacher education programs using experiential education models (Kenyan Institute of Curriculum Development, 2017; Wanyama & Chang'ach, 2013). Additionally, the nature of teacher appointments in Kenya has been criticized concerning their education programs, as each teacher is assigned to handle multiple subjects, including those they did not perform well on their secondary education (Hardman, Ackers, Abrishamian, & O'Sullivan, 2011). This has led to weak content knowledge transfer to learners, while also making the teachers confused in using appropriate pedagogical techniques based on the content. These issues are related to outdated and improper teacher education programs. The teacher training colleges in Kenya emphasize student-centered and interactive pedagogical methods (Katitia, 2015); however, in a research study by Hardman et al. (2009) on pedagogical practice in Kenyan primary schools, teachers reported not practicing student-centered learning in their classrooms, due to the influence of examinations, which demand priority and promote rote learning.

1.9.3 Untrained Teachers in sub-Saharan Africa

Challenges in teacher development further extend from quality to the quantity of trained teachers. However, a limited number of studies have examined and analyzed the phenomenon of untrained teachers. Seventeen thousand untrained teachers were hired in Malawi upon the introduction of free primary education to meet the schooling demand in 1995 (Kunje, 2002). The hired teachers were given a 2-3-week induction before starting their practice. Similarly, the introduction of free primary education in other SSA countries led to the hiring and training of untrained teachers (e.g., Tanzania - Komba & Nkumbi, 2008; Zimbabwe and South Africa - Mukeredzi, 2013; Kenya - Wanzare, 2002). By 2000, the percentage of untrained teachers in Malawi was 42%. Wanzare (2002) identified three major factors for low teacher quality in Kenya. (a) deficiencies in teacher pre-service training programs, (b) existence of unqualified and underqualified teachers, and (c) inadequacies in in-service teacher training programs. The author claimed that the demands increased because of government's adoption of free primary education, and the introduction of 8-4-4 (8 years of primary, 4 years of secondary, and 4 years of tertiary as a standard education pathway) education system made the existence of untrained teachers a permanent feature in the Kenyan education system.

However, there have been programs around the world that have benefited from hiring untrained teachers to meet demand and later successfully training them on-the-job. Two such examples still in operation are the Zimbabwe Integrated National Teacher Education Course (ZINTEC) and the Bangladesh Rural Advancement Committee (BRAC) program. ZINTEC offers residential vacation courses and a distance learning 4-year program (Chivore, 2002). The BRAC program provides introductory training and monthly learning committee meetings with individual mentors to untrained women teachers for rural areas (Lovell & Fatema, 1989). Both these programs reported higher achievement of teachers and students upon completion of the courses. These examples suggest the potential of successfully preparing untrained teachers through on-the-job professional development programs.

A study in Ghana profiled untrained teachers and concluded that Ghana has a substantial and significant number of untrained teachers who face difficulties in developing identity and skills as teachers due to limited mentoring and support (Tanaka, 2012). From these studies in Ghana, Malawi, and Bangladesh, it has been clear that the professional development of untrained teachers can result in successful teaching and learning opportunities through strategies of reflection, research, and mentoring.

1.9.4 Teacher Professional Development in sub-Saharan Africa

Research studies conducted in other regions of sub-Saharan Africa offer a broader perspective on the challenges in teacher development. Ahmadi and Lukman (Ahmadi & Lukman, 2015) problematized the neglect of teachers in decision-making and curriculum planning through their study with secondary school teachers in Nigeria. They identified ‘implementation’ as the single most crucial problem that curricular or pedagogical reforms face. The effectiveness of a curriculum is mainly evaluated based on its implementation and not alone on its design. Alao’s (2011) findings revealed through a quantitative study in Nigeria that 80% of sampled student-teachers believed the curriculum was not effectively implemented. One of the reasons the article offered as the cause was the non-involvement of teachers in decision-making and curriculum planning. The authors went on to recommend that teachers should be involved in the preparation of the curriculum, developing the process that would bring a sense of shared responsibility for its implementation and eventual success. In our engineering curriculum, both students and teachers have been involved from the beginning of the program in the design of the course. Inputs through

feedback sessions conducted through both in-person and virtual meetings shaped the course as it is running today. For example, one of the critical decisions championed by the teachers was in delivering the content on teamwork and the structuring of student teams based on the diversity and their knowledge of each students' strengths and weaknesses. Teamwork has been one of the successful elements of the program highlighted in multiple research studies we conducted (Radhakrishnan & DeBoer, 2016).

Multiple studies, though limited in terms of overall quantity compared to other regions, have provided recommendations for teacher development in SSA. Adewara and Lawal (2015) recommended open and distance learning (ODL) education for science teachers as the solution to problems of equity and access to teacher education in Nigeria. Kelani and Khourey-Bowers (2012), from their experience in Benin, established the importance of reflective practice in teachers based on Shulman's concept of pedagogical content knowledge. It was structured to develop the competency of teachers in more stable contexts and school systems. For example, at the end of each PD session, the teachers were required to present a journal of their reflections before the start of the next meeting. Then, they participated in the building of artifacts to demonstrate their knowledge of learned concepts. This way, the educators demonstrated practical and theoretical command of the content that they would eventually teach. Notwithstanding the level of detail put in the organization of these competency-building exercises, however, the authors noted that teachers who participated in the workshop did not fully gain self-sufficiency to go beyond what they had learned during training.

Hennessy et al. (2015) referred to their work developing educators in Zambia and recommended that professional development program should develop teacher agency and leadership, such that their growth is supported over time, encouraging not only the "effective integration of new pedagogies but the creation, adaptation, and refinement of the program themselves" (p. 559). A resultant effect of such focus would be the recruitment of the teachers as co-agents of change, who can be trusted to develop others. The second avenue for personal development is in the creation of opportunities for collaboration with colleagues within and outside workshops. The authors encourage engagement with the local community, which would improve "teachers' awareness of the local community as additional motivational and pedagogic support" (p. 560). They recommended encouraging and scaffolding teachers in obtaining resources that may

be otherwise unavailable to them. Such self-sufficiency seems pivotal to the independence that educators need to acquire to become competent instructors in the classroom truly.

Recommendations from both the studies in Benin and Zambia have played a considerable role in the design of this research study. Suggestions for applying reflective practice in the teaching context to heighten the self-awareness of individual teachers as to their practice and engaging them in a social process as co-agents to develop others provided the literature to guide the design phases in my study.

1.9.5 Teacher In-Service Professional Development in Kenya

In-service teacher training in Kenya has been consistently criticized over the past 20 years for being overly bureaucratic, under-resourced, poorly targeted and delivered, and largely ineffective in raising teaching standards (Lowe & Prout, 2019). There is a growing consensus among the nation's educational scholars on the key components that teacher development in the country should focus on, including attitudes and beliefs of a teacher towards teaching and learning (Kisangi & Ogwel, 2007), teacher competence in the areas of knowledge, understanding and practice (Bunyi, Wangia, Magoma, & Limboro, 2013), and pedagogical content knowledge (Ngware et al., 2013). Namunga and Otunga (2012) argued that Kenya needs to develop self-confident teachers who can perform their duties in challenging situations. However, traditionally there has been confusion in Kenya about what constitutes good teaching. Odhiambo (2008) and Odoul (2011) argued that "student exam success" is the predominant benchmark for good teaching in the country. Lowe and Prout (2019) discussed that Kenya acknowledges the importance of quality teaching, but there is uncertainty as to what it may look like. The authors also criticized the fact that in-service training received in Kenya is largely theoretical, making it difficult for teachers to connect theory with practice. Ngware, et al. (2013) identified that the in-service teacher training programs are planned to be conducted both formally and informally to meet the needs of teachers and head teachers in the areas of classroom practice and school management. However, in reality, such programs are rarely delivered (ibid, 2013).

Kisangi and Ogwel (2007) echoed the Ngware et al. (2013) report commissioned by the African Population and Health Research Center to investigate the quality and access to education in urban informal settlements in Kenya, pointing out that pedagogical content knowledge including group work, cooperative learning, and discovery approaches should be the key instructional

priorities. The authors also called for in-service training to include the concept of authentic learning. In addition, Kisgani and Ogwel (2007) noted that reflective component is essential during the professional development or else, the program "runs the risk of reinforcing traditional instruction or promoting practices misaligned with changing trends in education" (p. 1). Bunyi et al. (2013) also advocated for review of teacher education policy to formally embed in standards the notion of teacher as reflective practitioner. Lowe, Prout, and Murcia (2013) also acknowledged the importance of engaging teachers in reflective practice to strengthen a teacher's awareness and application of pedagogical content knowledge during in-service training in Kenya. Educational scholars researching in Kenya have also argued for TPD to address issues surrounding teacher identity and teacher mentoring (Kafu, 2011). Kafu argued that constructing teacher identity is essential to fully understanding and performing the role.

Wanzare and Ward (2000) summarized 21st century priorities for teacher development in Kenya. They are: staff development on relevant classroom practices and ICT skills; teacher empowerment using autonomy, responsibility, self-direction, and reflection; instructional supervision and evaluation geared towards supporting teacher learning in schools; external support by strengthening links with supporting organizations; and induction and school contribution for internal teacher support. They concluded that in-service training should be continuous, and school based. Finally, Lowe and Prout (2019) developed key recommendations for in-service training in Kenya based on their literature synthesis in the field. Three specific recommendations offered by them offer valuable insight to my research.

1. In-service training to be reframed to address fundamental issues surrounding teacher identity and how students learn in terms of building pedagogy and a professional approach to teaching;
2. In-service programs have to be localized instead of the current centralized system with more inputs from local school heads on their specific needs
3. In-service training should be sensitive to local pressures and constraints and pay attention to accommodate indigenous knowledge.

There is consensus within the Kenyan government regarding the need for effective in-service teacher training, as it is necessary to raising teaching standards, which is fundamental to the nation's capacity building. In 2017, the Kenyan Institute for Curriculum Development launched a reformed basic education curriculum framework in 2017 modeled as a "Competency-

based curriculum" with a vision to enabling students to become engaged, empowered, and ethical citizens by equipping them with 21st century knowledge and skills (Kenyan Institute of Curriculum Development, 2017). The new curriculum proposes three different pathways for learners entering senior school. They are: Arts and Sports Science, Social Sciences, and STEM (see Appendix B). The pathways designed are based on various government-initiated task force studies and research-informed calls for educational policy changes that were reviewed above. Within the three pathways, schools are encouraged to offer various tracks. Under the STEM pathway, a learner can opt for one of four tracks. They are: pure sciences, applied sciences, technical and engineering, and careers and technology studies. The reformed curriculum is expected to help provide resources and educational framework to build the country's capacity in science, technology, engineering, and innovation which are considered the key areas for economic and human development in the Kenya Vision 2030 report (Ndung'u, Thugge, & Otieno, 2011). The curriculum reform was made at a crucial time with a growing consensus and significant efforts around the world to improve the focus and development of STEM to support the economies. The STEM pathway in Kenya aims at developing the individual learner's innovativeness and promoting the use of technology to develop a labor force that will drive the Kenyan economy. The curriculum reform places a strong emphasis on the role of the teacher and defines it as:

> The teacher acts as a facilitator who encourages students to discover principles for themselves and to construct knowledge by working, answering open-ended questions and solving real world problems. To do this, a teacher should encourage curiosity and discussion among his or her students as well as promoting their autonomy. In scientific areas in the classroom such as STEM, constructivist teachers provide raw data and physical materials for the students to work with and analyze. (Kenyan Institute of Curriculum Development, 2017, pp.61-62).

The curricular reform proposes a phased approach of implementation starting with lower primary (grades 1-3) and changing the curriculum to a higher-grade grade every year. Since, the implementation in 2019 several critiques have been made on the curricular reform. One of the key critique has come from the Kenya National Union of Teachers via a research undertaken that found that majority teachers were not adequately prepared for the change in content and teaching methods, and most teachers were not trained and those that were trained found the training inadequate. Therefore, alternative modes of training teachers are vital in order to meet the full potential of the Competency-Based Curriculum.

Besides the recommendations for preparing teachers as reflective practitioners, and engaging them as co-agents, gaps identified in in-service training specific to Kenya, such constructing teacher identity, driven by localized needs, preserving indigenous knowledge, and building the self-confidence of teachers through development of pedagogical content knowledge offers key insights to the design of my research. This understanding is strengthened through the identified theoretical framework of situated learning theory and communities of practice.

1.10 Theoretical Framework

1.10.1 Situated Learning

Multiple learning and development theories provide lenses to guide research on teacher development. These theories include Constructivism (Piaget, 1964), Social constructivism (Vygotsky, 1987), experiential learning (Dewey, 1938), and situated learning (Lave, 1991). Situated learning theory also can collectively represent the critical tenets of social constructivism and experiential learning in research on teacher professional development. According to Dewey (1938), learning is a democratic and social process, and at the same time, should embody what is personally meaningful to individuals. According to Vygotsky (1987), knowledge is socially constructed and gained by the means of moving into the Zone of Proximal Development (ZPD). Lave and Wenger's (1991) theory pertains to the situated social process, shared beliefs, and support for learning within communities of practice. Therefore, I choose situated learning as my theoretical framework and describe its application in my research below. Situated learning provides a structural framework for this research for three reasons.

First, situated learning posits that learning is a social process whereby knowledge is dynamically constructed and is situated in a specific context and embedded within a particular social and physical environment. This notion provides the lens to view the teachers' relationships with each other as they engage in reflective and dialectic knowledge discourse. This perspective of learning as a social and situated process aids in overcoming criticisms surrounding conventional methods of teacher education research, where teacher development is focussed on the individual and the subject matter knowledge. Moon (2007) concluded from a multi-year teacher development study in SSA that successful ongoing teacher education and development must be a social process, and I apply situated learning theory and demonstrate as such.

Some studies on teacher education have concluded that there is no convincing evidence that teacher education makes a difference (Cochran-Smith & Zeichner, 2009), while some have found that teacher education based on specific pedagogies has the potential to influence the practices of teachers (Brouwer & Korthagen, 2005). This contradicting and simplistic view of teacher education is ascribed to the fact that researchers often look at teachers and schools from "outside." Anderson and Herr (1999) called for an "insider perspective" using qualitative approaches to obtain the description of real-world experiences of the teachers, and they discovered that what was going on inside the schools looked different from what university researchers expect and describe. By taking an insider qualitative approach through the framework of situated learning, I intend to gain a profound understanding of training teachers to facilitate engineering from the perspective of "societally significant practices" (Chaiklin & Lave, 1996, p.378). For example, as described by Lave & Wenger (1991), much of the learning taking place in teachers appeared to have the characteristics of apprenticeship learning (Korthagen, 2009), similar to what Lave saw happening in novices entering a community of Liberian tailors (Lave & Kvale, 1995). This notion supports the idea of making the TPD a social process.

Second, a primary component of situated learning is *in situ* learning or "learning by doing." Learning is viewed as "an integral part of a generative social practice in the lived-in world" (Wenger, 1998, pp.35). Thus, learning occurs in authentic activities, or the everyday activities and social practices, of individuals engaged in a Community of Practice. This view encourages me to investigate the context and culture that the teachers are part of, and the experience that they reflect on. In a situationist perspective, learning is described as the "movement from peripheral forms of participation in a CoP to full participation facilitated by apprenticeship opportunities to observe and the practice" (Lave & Wenger, 1991, pp.5). Teaching knowledge cannot be simply transmitted to teachers with the expectation of resulting improved actions. Situated learning theory argues that the opposite is true: learning emerges from our own actions in relation to those of others. Thus, the learning outcomes are socially constructed. This component drives the decision to design TPD, where teachers engage in development as they continue their practice.

Third, as part of legitimate peripheral participation, "a person's intentions to learn are engaged, and the meaning of learning is configured through the process of becoming a full participant in sociocultural practice" (Lave & Wenger, 1991, p.29). This notion allows us to understand the extent and ways of participation of teachers who have a common goal. Situated

learning also lends us the framework for questioning the meaning, practice, community, and identity of the individuals as they engage in the process of knowledge acquisition. Within this model, meaning refers to "a way of talking about (changing) ability-individually and collectively-to experience our life and the world as meaningful" (Wenger, 1998, p.5). Practices involve shared historical and social frameworks that "can sustain mutual engagement in action," whereas the concepts of community and identity provide a means of "belonging" and "becoming" within the learning process.

In this design-based research study, I use these four components as my qualitative analysis coding scheme. Investigating the knowledge and skill development of teachers of the three elements of a CoP (described in detail below), I analyze the qualitative data by looking at how teachers describe their experiences via these four major constructs of meaning, practice, community, and identity (explained in detail under the Data Analysis section).

1.10.2 Communities of Practice

Situated learning theorizes that learning is experienced and mediated through relationships with community members or within a "community of practice." Within a CoP, group members jointly share and develop practices, learn from their interactions with group members, and gain opportunities to grow personally, professionally, and/or intellectually (Lave & Wenger, 1991). Wenger (1998) suggests that the combination of a shared domain of interest, mutual engagement within the community, and shared practices are three essential features that constitute a CoP. The three inter-related components and their interaction align with my research question: a domain (a shared area of interest – *engineering*), a community (the close-knit group of teachers and the researcher working with them – *teamwork*), and practice (mutual engagement towards action – *teaching*) (Figure 5).

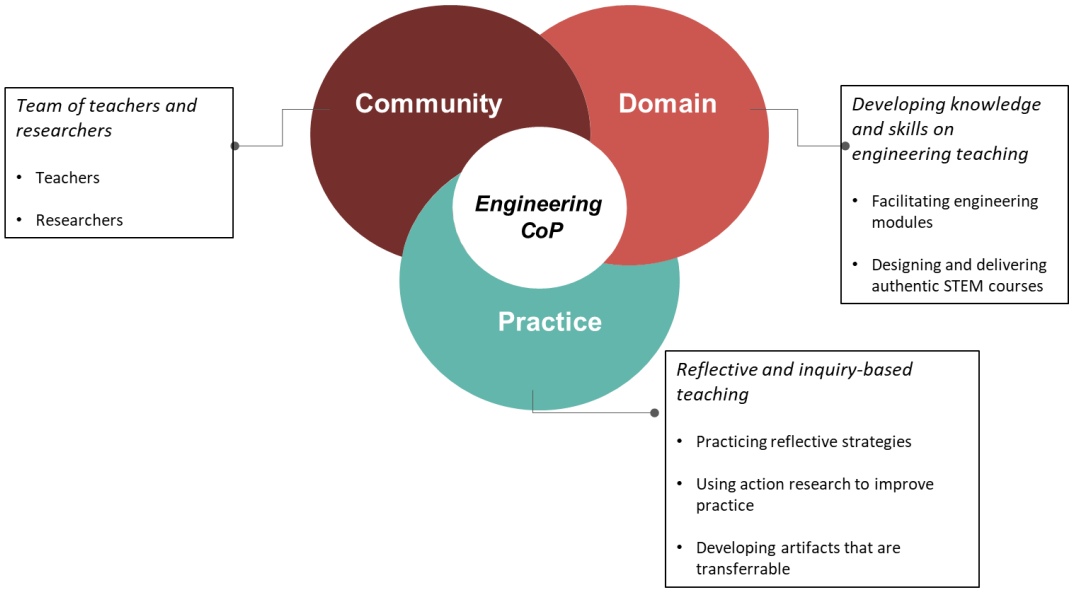

Figure 5. The inter-related elements of Engineering-CoP (E-CoP) in this DBR study

In combining these three elements, the activities of the CoP do not occur in isolation within a community but instead are based on an array of relations. The individual learner is, therefore, defined by these relationships within the community. As such, learning becomes embedded within a social context, and social membership, identity, and knowledge are mutually dependent (Mills, 2011). To examine engagement within these engineering teachers, CoP, the three dimensions that constitute a community of practice will be explored: joint enterprise, mutual engagement, and a shared repertoire. These three elements guide the actions that must be taken (like for shared repertoire, continuous development and maintenance of procedures, techniques, tools, symbols, concepts, etc., must be done) and principles that must be adhered to (like for joint enterprise, unifying goal must be established and actions taken must be coherent; for mutual engagement, members must continuously engage and maintain interactions) for participating in a community of practice.

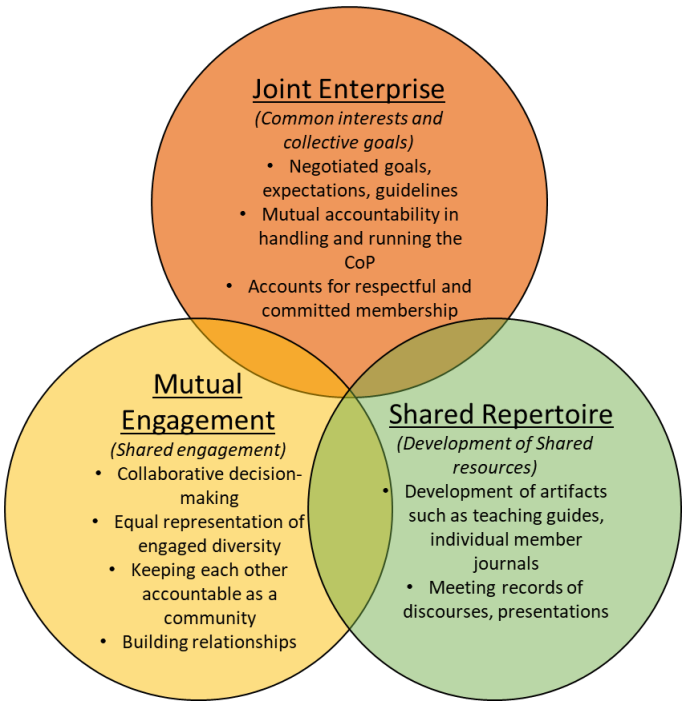

Figure 6. The three dimensions constituting the community of the Engineering-CoP in this DBR study

The first dimension, joint enterprise implies that the community possesses common interests and collective goals. Membership involves a commitment to an endeavor that is considered relevant to all members of the community, and mutual accountability becomes an integral part of the practice. The second dimension, mutual engagement is a fundamental characteristic of a community of practice. Membership is, therefore, developed through shared engagement in discussion, negotiation, and exchange. Mutual engagement creates relationships among people; however, mutual support and accountability cannot always be assumed. Conflict, disagreement, and challenge can often be typical forms of engagement within a community of practice. Wenger (1998) suggests that "as a form of participation, rebellion often reveals a greater commitment than does passive conformity" (p. 77). As such, the multiplicity of relations within a community of practice is diverse and complex. Among others, mutual relations could include those of expertise and helplessness, ease and struggle, resistance and compliance, and trust and suspicion. The third dimension of a community in CoP is the creation of a community in which members develop a shared repertoire of resources. Such resources could include shared artifacts, discourse, narratives,

and points of reference. As a result of the continued maintenance and development of a shared repertoire, Wenger (1998) suggests that the members are given a sense of identity, shared membership, and belonging within a community.

According to Wenger (1998), these three dimensions are what sustains and propels the functioning of a CoP. Therefore, considering the end goal for this continuous professional development is to create a self-sustaining CoP, the professional development interventions must focus on building the three dimensions of the community: joint enterprise, mutual engagement, and shared repertoire. Situated learning theory guiding the establishment and operations of a CoP fits this DBR of engineering teacher professional development. I acknowledge the extensive evidence of using CoPs as a means of teacher professional development across the world (e.g., Akerson, Cullen, & Hanson, 2009; Cochran-Smith & Lytle, 1999; Mills, 2011; Schlager & Fusco, 2003) and also in STEM fields (Johri & Olds, 2011; Liu, Carr, & Strobel, 2009). However, the unique nature of this research extends the possibility of evaluating CoP in a fragile context for untrained teachers to practice engineering teaching and learning. Given the complexity of the program the teachers have to master, including but not less than, technology, new pedagogical practices, new content knowledge, and teamwork, I hope that analyzing the professional development in regards to the context and cultural background of the community will result in a more productive outcome of the design principles for such programs.

1.10.3 Adoption of the Theoretical Framework in the Design of the Study

Situated Learning and Communities of Practice provided the framework for both the design of solutions and evaluation through research. I discuss below my reflections on the ways we adopted the critical facets of theory in the DBR study.

Formation of community: In order to begin the engineering teacher professional development, understanding of the system, challenges, and uncertainties specific to the Tumaini context were necessary. The teachers were the most knowledgeable on the context, and culture of the community. Therefore, as discussed in the CoP, the teachers had to develop a community and mutually engage. Therefore, we started with collaboration as the first step for the teachers to come together as a team and critically examine the shared histories of the organization.

Negotiating meaning: As the teachers were teaching engineering for the first time, and were motivated to pursue it long-term, it was necessary that they understood the practice of engineering and found it meaningful. CoP discusses negotiation of meaning as a result of continuous engagement in the practice and improving it. Therefore, the professional development was planned as the teachers were teaching engineering to make meaning of their actions and see their efforts as worthwhile to achieve students' learning outcomes.

Interconnections to practices: For the teachers engineering teaching was not their primary practice, therefore it was important for them to see the relevance of learning and developing identity in a new practice was beneficial to their other practices. CoP discusses boundary objects and boundary connections as ways that members make connections to other practices. Therefore, for the TPD to be sustained, teachers needed to identify the boundary objects from their practice of engineering teaching and bridge it to other practices/areas of work.

Construct an Identity: Motivated for a long-term endeavor the teachers need to develop an engineering teacher identity. CoP discusses construction of identity via negotiation of the experience, membership in the community, continuing to be on a learning trajectory, and meaningfully connecting multiple practices. Therefore, for the teachers to develop an engineering teacher identity, they needed to participate fully in practice, in the community and identify themselves as engineering teachers.

To achieve these facets, a single intervention or a short-term teacher professional development program and evaluation were not ideal. Therefore, I needed a research method that provides the guidelines while recognizing the flexibility to analyze needs, create solutions, test, and make changes as needed.

1.11 Research Methodology: Design-Based Research

Design-Based Research is a methodological approach created by learning scientists in which researchers investigate solutions to educational problems by designing interventions and iteratively testing them in real-world settings to see how they function in formal or informal educational settings (Barab & Squire, 2004; Fishman, Penuel, Allen, Cheng, & Sabelli, 2013). DBR was generated from the need for a research methodology that closely linked and directly applied research into the real-world of educational practice. Van den Akker and Plomp (1992, p.2) wrote, "traditional research approaches such as experiments, surveys, correlational analyses, with

their emphasis on description hardly provide prescriptions that are useful for design and development problems in education." DBR "was introduced with the expectation that researchers would systematically adjust various aspects of the designed context so that each adjustment served as a type of experimentation that allowed the researchers to test and generate theory in naturalistic contexts" (Plomp, 2013, pp.12). Kolmos (2015) presented a case of DBR as a much-needed strategy in engineering education, where "it has the potential to develop change agents who are familiar with the context, culture, the subject area, and new teaching and learning methods, and who can facilitate the transformation of practice in collaboration with local academic staff" (p. 373).

Before explaining how DBR has guided my research investigation, I briefly summarize the distinctive characteristics of DBR compared to other research methods. Research methods are chosen based on their applicability to best present outcomes of the primary research function. DBR scholars (McKenney & Reeves, 2018; Plomp, 2013) explain that there are five research functions: to describe, to compare, to evaluate, to explain or predict, and to design and develop. In many research projects, more than one of these research functions might be needed to carry out the primary role. The primary research functions that DBR is applicable for my research are the functions of design and development. An essential characteristic of DBR is that there are two possible purposes for using DBR. Plomp (2013) describes the two goals as development or validation. In the case of a developmental DBR, the purpose of DBR is to develop research-based solutions for complex problems in educational practice. Whereas, in validation studies, the goal of DBR is the development or validation of a theory. McKenney and Reeves (2013) characterize this difference between purposes as research *on* interventions and research *through* interventions. My goal is developmental, as I hope to develop and evaluate the educational interventions with the dual aim of generating research-based solutions for the problem of continuous professional development of engineering teachers in fragile contexts and advance the knowledge about the characteristics of the intervention and the process of designing and developing them in collaboration with the participants. Anderson and Shattuck (2012) listed aspects that suggest a quality DBR study. I enumerate these qualities and explain how they are applied in my research in Table 2.

Table 2. Aspects of a quality design-based research study

Qualities by Anderson and Shattuk (2012)	*How is it met in this research?*
Being situated in a real educational context	The research study is situated in the practitioner's context of an alternative residential school where the educational problem of developing untrained teachers' knowledge and skills for engineering facilitation is being addressed.
Focusing on the design and testing of a significant intervention	In attempting to solve the educational problem through three cycles of iteration, three interventions, each linked to one another is designed and tested.
Use of mixed methods	Using a qualitative approach, different data sources are collected through a continuous timeline and analyzed using methods suited for the research questions.
Involving multiple iterations	Through the implementation, all the intervention strategies take multiple iterations with a focus towards an improved system of using the approach in the context of practice. E.g., the reflective practice strategies intervention continued to be revised and redesigned based on the inputs of the teachers and challenges faced during implementation.
Involving a collaborative partnership between the researcher(s) and practitioner(s)	As explained in the section above on 'Consultation with experts and practitioners,' the entire research study has evolved in close collaboration with the teachers, and through constant negotiations resulted in the design of interventions, and the research study itself.
Evolution of design-principles	One of the expected outcomes of this research study is to develop design principles by evaluating the applicability of a CoP in navigating the intervention strategies for the professional development of teachers.
The practical impact on practice	Resulting design principles and evaluation of the theory will directly impact how the teacher professional development in fragile contexts must be considered. Also, through the interventions, the teachers will have an immediate impact on their practice.
Educational Problem at the center of DBR (Added quality by McKenney & Reeves (2013) from their response article to Anderson and Shattuck)	The problem at study is the lack of engineering education professional development models for untrained teachers and, in particular, to fragile contexts. Via this DBR study, analyzing the knowledge and skill development of teachers participating, I expect to frame design principles that will guide professional development for such a unique population.

Different authors have different views of what design-based research looks like, but they all agree that this type of study consists of several phases (Hakkarainen, 2009, p.12; McKenney & Reeves, 2018; Plomp, 2013, p.19; Van den Akker, 2007). One of the famous illustrations to depict the process of design-based research is that of Reeves (2006, p. 59). He represents the design-based research approach, as shown in Figure 7, calling it the refinement of problems, solutions, methods, and design principles. McKenney and Reeves (2012) developed three core iterative phases (analysis, design, and evaluation, with each identified as a 'micro' cycle, described below), resulting in the understanding of theory and development of practice as the final phase (reflection). Combinations of micro-cycles are termed as meso-cycles, and meso-cycles together are termed as a macro-cycle.

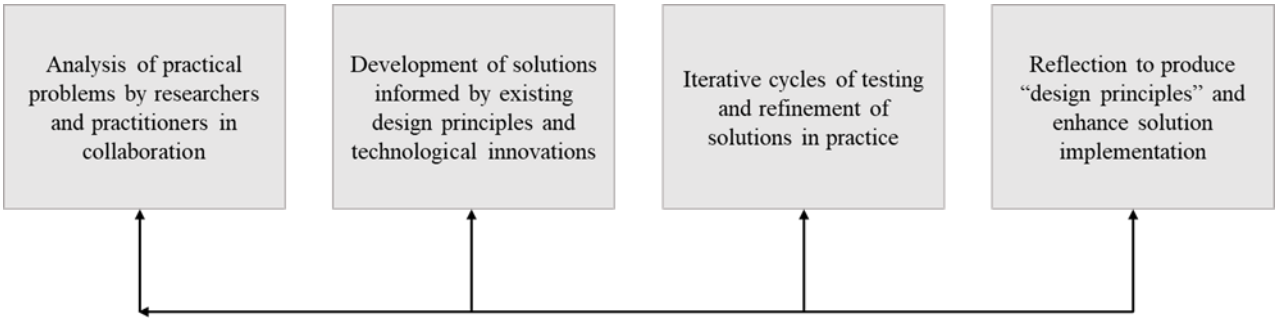

Figure 7. Design-based research approach (Reeves, 2006, pp. 59)

Analysis, Design, and Evaluation

The analysis is aimed at understanding how to target a design. The two main activities in the analysis phase are needs and context analysis and a literature review (McKenney, Raval, & Pieters, 2012). Design involves constructing and implementing educational solutions. It also requires prototyping of the design product (or process) through formative evaluation and systematic revision of the design. Evaluation is the final stage in the design where appropriate research and/or evaluation tools are used to measure the outputs that can inform the next cycle. In chapters 2, 3, and 4, I use these three micro-cycles to discuss the three phases.

1.11.1 Implementation of DBR

In the following section, I will outline the identification of intervention strategies, and the model of design and development of each. Figure 8 describes the overall research outline using design-based research cycles.

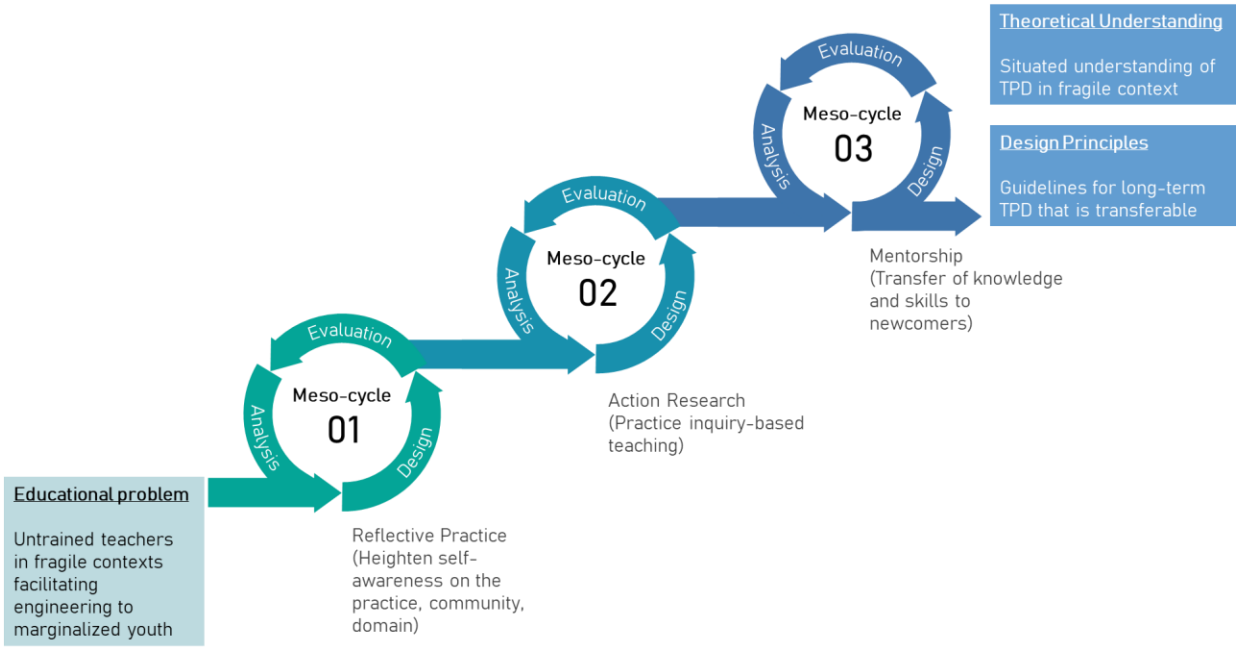

Figure 8. Design-based research outline for this study

In this chapter, I have referred to my research as three distinct studies that cover the three meso-cycles (figure 9), that have been initiated in my multiple years of research and collaboration with the center. The three meso-cycles explain different strategies applied in complementary to each other to improve the teachers' knowledge, skills, and attitudes in teaching engineering. Each of the three studies informs the overall RQ proposed.

Meso-cycle 1 covers a three-month intervention of the untrained teachers using reflective practice strategies. Analysis of the problem ahead of this intervention resulted in identifying the challenges the teachers were facing. For example, for the first time all three teachers had to work as a team and were met with challenges in terms of coming together as a community, lack of opportunities to develop a sense of meaning to their practice, and limited knowledge and awareness with the field of engineering. Reflective practice (Schön, 1983) was identified as the design

solution to heighten their awareness levels and develop the meaning of their practice, community, and the domain. In line with the situated learning theory and CoP, using reflective practice was hypothesized to establish the foundation for long-term professional development. Evaluation of this intervention demonstrated that reflective practice has formed a sense of community amongst the teachers and has initiated the steps towards meaning making and building engineering identities.

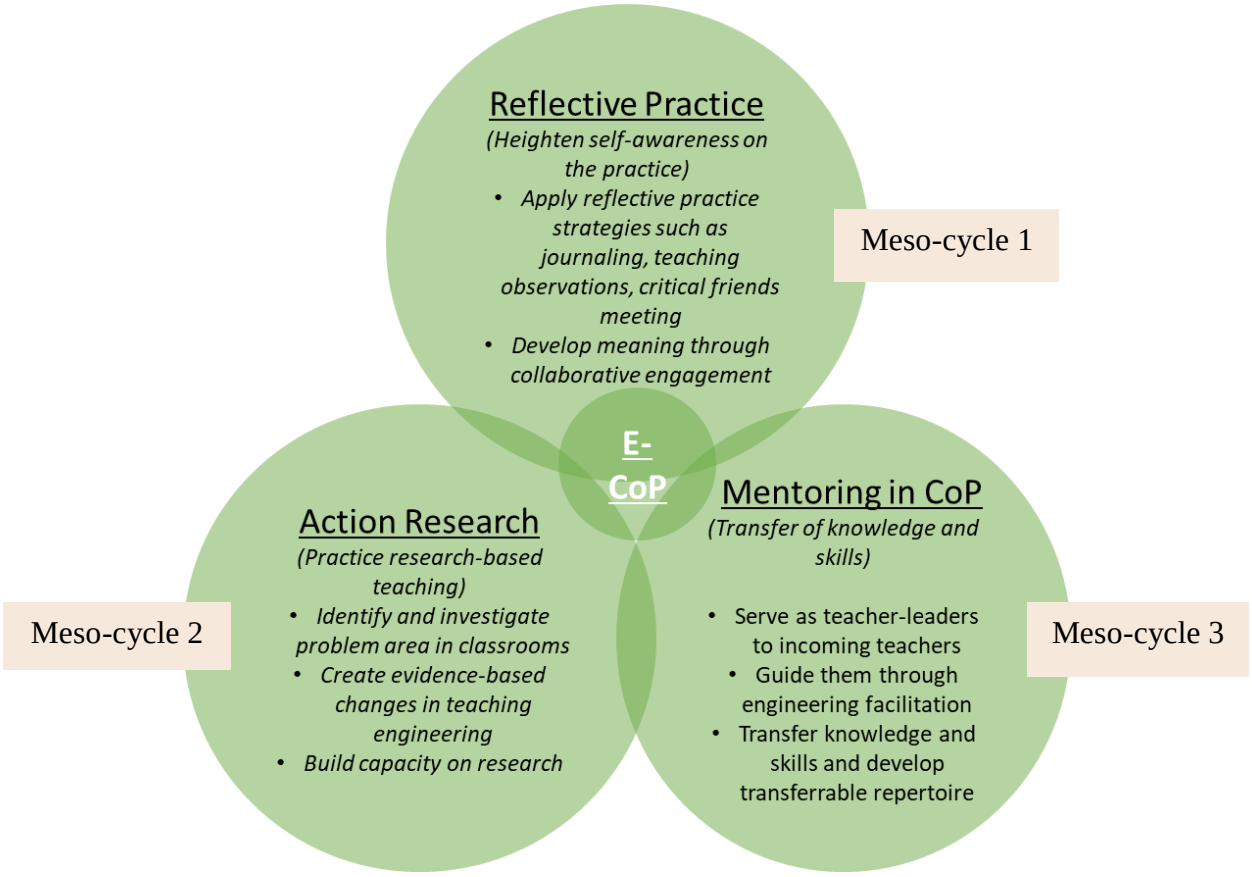

Figure 9. DBR Interventions to build the elements that constitute a CoP

Meso-cycle 2 covers a nine-month intervention of advancing their knowledge and skill development initiated through reflective practice by using action research in their classrooms. The first intervention also revealed the challenges the teachers continued to face in their pedagogical practices, such as delivering active classes, coordinating teamwork amongst students in classrooms, and comprehending and teaching complex technical content.

Action research studies have shown that the ability for instructors to research in their teaching environments leads to development in self-understanding of the practice, the discipline, and the "own-selves" (Goodnough, 2001). This on-going intervention has teachers identify a problem area of interest to them, and investigate through the action research cycles of plan, act, observe, and reflect. A research study by Kunje and Stuart (1998) in Malawi, studying the untrained teacher's professional development using action research, reported that the untrained teachers were ready to embrace development opportunities through reflection and research compared to their trained colleagues. However, the researchers critiqued their program's sustainability saying lack of resources and a localized trainer to be situated in each school they worked with lead to challenges and ending the program. Considering the importance of consistent support on the ground, in this design-based research study, I embraced the opportunity to be on the ground for a more extended period (One year, from Jan.2019 to Jan. 2020). Situating myself for a longer time in the context was also with the hope of gaining an insider relationship and perspective of the setting. Results from this cycle provided insights into the complex interplay of untrained teachers' development as both engineering instructors and teacher-researchers.

Meso-cycle 3 covered a five-month intervention (planned for nine months, discussed in detail in chapter 4), where the three teachers practiced mentorship for incoming engineering teachers. Due to Tumaini's need to expand and cater to a higher number of street-youth and given the uncertainties in the field of development based on funding opportunities, the center grew in size from 18 students in December 2018 to 29 students in January 2019. The center's expansion was possible with the opening of the new vocational school space. To meet this growing demand, the LED program had to speed up the process of having new engineering teachers. Therefore, since February 2019, the CoP has expanded with four new vocational teachers taking part in professional development. Between February to April 2019, the CoP meetings primarily catered to devising system and structure to the second iteration of the on-going engineering curriculum involving a higher number of user-centered projects. From August 2019, the three senior teachers took up mentoring responsibilities and guiding the newcomers into the CoP. According to Lave and Wenger, the sustainability of a CoP hinges on the increasing membership over periods, where newcomers are welcomed and guided by the senior members, resulting in the transfer of knowledge and skills through 'legitimate peripheral participation' (Lave & Wenger, 1991). This

planned intervention built the capacity of teachers as mentors and advanced the development of the elements of a CoP.

The three meso-cycles were investigated as individual research studies contributing to three research papers. Through this dissertation, I synthesized the three studies at the end to develop 'design principles' and reflect on the applicability of a CoP in a fragile context during phase 4 (reflection) of the design-based research. In the following tables 3, 4, and 5, I discuss the micro-cycles carried out under each meso-cycle with descriptions on the process and research quality requirements.

Table 3. Meso-cycle 1 (3 months): Enactment of reflective practice strategies

	Micro-cycle 1: Analysis	Micro-cycle 2: Design	Micro-cycle 3: Evaluation
	Literature and Interview (prior research in the context)	Reflective Practice (RP) strategies	Qualitative research
Purpose	Gain understanding of challenges in implementing engineering course in low-resource context Baseline for developmental and redesign process	First design of the TPD to increase a sense of the teachers engineering teaching conditions - Implementation of reflective practice strategies (journaling, observation, critical friends meeting) identified in collaboration with teachers	Identify the use of reflective practice strategies in development of teacher's development in knowledge areas of engineering, teaching, and teamwork; ***Constructs:*** Practice, Community, Meaning, and Identity (SL and CoP constructs)
Instrument	Semi-structured interview (students & teachers)	Construction of implementation plan; Development of collective goals, expectations, and guidelines	Final semi-structured interviews, journaling, critical friends meeting, WhatsApp conversations;
Credibility	Spending extensive time with the teachers; Open meeting discussions	Monitoring and Evaluation by teachers and researcher over critical friends' meetings	Triangulation
Dependability	Step-by-step transcription; verification through discussion with research mentors	Evidence-based design of strategies (Obtained from scholarly research)	Thematic analysis (established analysis procedure)
Confirmability	Member checking		Member checking

Table 4. Meso-cycle 2 (9 months): Enactment of Action Research

	Micro-cycle 4: Analysis	Micro-cycle 5: Design	Micro-cycle 6: Evaluation
	Micro-cycle 3 Evaluation and Literature	Action Research (AR)	Qualitative research
Purpose	Clarify findings from Micro 3 evaluation - RP strategies established foundations of a community - Improving practice, meaning generation, and identity formation - Challenges continuing in specific content, pedagogical techniques, and understanding classroom Identify additional strategies to achieve TPD goals (refinement)	Applying classroom action research in each teacher's classroom/topic of interest to strengthen results of RP and practice evidence-based teaching; - Each teacher to conduct an action research study - Based on the study, design own 'changes' to practice and conduct cycle 2 of AR to evaluate 'change' - Develop meaning of practice, community, and continue to grow engineering identity	Understand the role of AR in development of teacher's development in knowledge areas of engineering, teaching, and teamwork; Identify acceptability of AR as a new practice within the CoP **Constructs:** Practice, Community, Meaning, and Identity (CoP components)
Instrument	Instruments used for Micro-cycle 3 evaluation	Training on research and development of research components (journals)	Semi-structured interviews, journaling, critical friends meeting, WhatsApp
Credibility	Spending extensive time with the teachers (on the field and face-to-face); Open meeting discussions	Monitoring and Evaluation by teachers and researcher over critical friends' meetings	Triangulation
Dependability	Step-by-step transcription; verification through discussion with research mentors	Evidence-based design of strategies (Obtained from scholarly research)	Thematic analysis (established analysis procedure)
Confirmability	Member checking		Member checking

Table 5. Meso-cycle 3 (6 months): Expanding CoP with new engineering teachers

	Micro-cycle 7: Analysis	Micro-cycle 8: Design	Micro-cycle 9: Evaluation
	Micro-cycle 6 Evaluation and Literature	Mentoring in an expanding CoP	Qualitative research
Purpose	Clarify findings from Micro 6 evaluation Identify additional strategies to achieve TPD goals (refinement)	Increasing the size of CoP by welcoming new engineering teachers to allow old-timers to mentor newcomers in legitimate peripheral participation	Understand role of mentoring newcomers in the transfer of knowledgeable skills, and generated community-based repertoire to enact transformations **Constructs:** Practice, Community, Meaning, and Identity (CoP components)
Instrument	Instruments used for Micro-cycle 3 evaluation	Training on being a mentor; Plan development for mentoring newcomers (discussions)	Semi-structured interviews, journaling, critical friends meeting, WhatsApp
Credibility	Spending extensive time with the teachers (on the field and face-to-face); Open meeting discussions	Monitoring and Evaluation by teachers and researcher over critical friends' meetings	Triangulation
Dependability	Step-by-step transcription; verification through discussion with research mentors	Evidence-based design of strategies (Obtained from scholarly research)	Thematic analysis (established analysis procedure)
Confirmability	Member checking		Member checking

1.11.2 Limitations to DBR and Positionality

Despite the numerous articles commending the benefits, there have also been useful critiques (Barab and Squire, 2004). Barab and Squire argued that "if a researcher is intimately involved in the conceptualization, design, development, implementation, and researching of a pedagogical approach, then ensuring that researchers can make credible and trustworthy assertions is a challenge" (p. 10). This challenge is a familiar one in qualitative research in that none of the methods can or do claim that the researcher's bias is removed from the research process (Creswell & Miller, 2000). Indeed, some qualitative proponents argue that the researchers, with their preferences, insights, and deep understanding of the context, are the best research tool themselves (Shenton, 2004). Several ways have been suggested to minimize this concern in DBR as well as other qualitative methods (Onwuegbuzie & Leech, 2007), and I argue that this inside knowledge adds as much as it detracts from the research validity. I minimized the bias by adopting two of the five techniques discussed by Lincoln and Guba (1985) to establish trustworthiness. They are: (i) activities increasing the probability that credible findings will be produced (prolonged engagement, persistent observation, and triangulation) and (ii) an activity providing the direct test of results and interpretations with human sources (member checking). Referring to the tables 3, 4, and 5, I perform each technique in the first activity in each micro-cycle to ensure credibility: prolonged engagement with teachers and context (Micro-cycles 1, 4, 7), persistent observation through monitoring and evaluation (Micro-cycles 2, 5, 8), and at last triangulation and member checking (Micro-cycles 3, 6, 9).

Another concern raised in using DBR is its applicability in short-term projects, especially in doctoral dissertations. Most literature agrees that design-based research is a long-term approach which contains multiple iterations of design, development, and revision (Amiel & Reeves, 2008, p.35; Burkhardt & Schoenfeld, 2003), but this is not always possible with the short time frame required in a master's and Ph.D. study (McKenney & Reeves, 2012, p.188). This raises the issue of how design-based research can be effectively implemented in a thesis or dissertation, and specifically, how many cycles are sufficient to produce valid and significant design principles in a relatively short-term project. Herrington et al., (2007) claim that this does not mean that graduate students cannot conduct educational design-based research, it emphasizes the importance that graduate work should be undertaken in the form of micro- and meso-cycles (Pool & Laubscher,

2016). In this dissertation, I address these critiques by undertaking a research scope that has spanned over two-years, with enough time to run each micro-cycle and meso-cycle its natural full course by accommodating the changes demanded by the context. Therefore, by being able to run three meso-cycles to address the educational problem under investigation, I argue that sufficient evidence has been generated to produce valid design principles.

The systematic literature review by Anderson and Shattuck (2012) also presented the lack of DBR usage across demographics and research areas. Among the 45 DBR articles identified in their analysis as significant from journal publications, no article was reported as undertaken in low and middle-income countries, and only 9% (~4 articles) of the articles focused on teacher training and professional development. This gap in methodological literature in the context of SSA and teacher professional development limits the knowledge of applying DBR in these contexts.

1.12 The teacher participants

The three teachers in the study are Ellie, Sandra, and William (pseudonyms are used to provide anonymity for the participants). Ellie and Sandra joined as course instructors after six months from the start of the curriculum. William initially took a secondary role as a course instructor. The lead instructor appointed initially for this course quit his position with TIC after four months. Ellie, Sandra, and William became lead teachers based on increased student enrollment at the center. During this study, the course was conducted on multiple days of the week, and therefore, the three teachers shared primary responsibilities and split their schedules. Tumaini functioned on the Kenyan formal schools' timetable, which is three months (Jan-Mar; May-July; Sept-Nov) of education and the following month (Apr, Aug, Dec) for vacation. Therefore, the LED program was taught for nine months in total annually.

Ellie: Ellie joined TIC as a volunteering intern during the latter year of her bachelor's degree in education in Early Childhood Development and has continued to serve as a teacher for the past two years. Among the three teachers, Ellie is the only one who had a formal background in education, but even she had no prior teaching experience. Ellie, when she started to work at Tumaini, initiated and continues to teach literacy courses (English and Kiswahili) for all grades of students. Ellie was inducted as a full-time employee and appointed as the headteacher in 2017. Ellie became the primary engineering instructor for nine new students who came into the center in

2017. This group of students was referred to as the junior class. In 2018 and 2019, she was one of the engineering instructors for the primary students.

Sandra: During the start of the study, Sandra was working on her bachelor's degree in economics at a local university. Sandra joined Tumaini as an intern. Sandra was inducted as a full-time employee in the year 2017. Sandra also served as the human resource manager, fundraising coordinator, accountant, and farm manager at Tumaini. In 2017 and 2018, she instructed classes on science, mathematics for both junior and senior levels, as well as the engineering course for the senior class. She collaborated with William in teaching the senior class. In 2019, she was one of the engineering instructors for the primary students.

William: During the course of the study, William served as the senior staff member of Tumaini. William started as a volunteer teacher and social worker for Tumaini. He was promoted to a full-time social worker and teacher in 2017. During this study, William taught science, social studies, and engineering classes. In 2017 and 2018, he collaborated with Sandra on planning and instructing the engineering classes for the senior students. In 2018 and 2019, she was one of the engineering instructors for the primary students.

1.13 Positionality

The positionality of a researcher plays a vital role in qualitative research. I, as the researcher, combined multiple roles throughout the study – that of facilitator, co-designer, co-researcher, leader, critical friend, and CoP member. There were some natural advantages of combining these roles. By acting as a co-designer, co-researcher, and facilitator, I had a direct impact on practice through the development of design solutions that were both theoretically viable and responsive to the ground realities. As a member of CoP, I had an 'insider' (Merriam et al., 2001) view of the institutional reality, which may not have been accessible to an external researcher. This helped me influence the integration of design and data collection activities seamlessly into the ongoing program strategy development and program evaluation. Being acknowledged as a "Tumaini person" happened after years of engagement with the community of Tumaini. The teachers over the time have shared with me that initially (in 2016), they were very uncomfortable with me as they saw me as only a teacher. Because the director of Tumaini convinced the teachers that they needed to work with me closely, they agreed. They mentioned me as a "human-robot" who would come and

deliver instructions for them and leave. During the initial days, my role during the time at Tumaini was utterly professional, and I treated it as a workspace.

However, due to my friendship with the director of Tumaini, outside the worktime, he played an advocate role for me and informed the teachers, I could be a "friend." I quickly learned that the culture of Tumaini, irrespective of the time and place, was always a balance of both professional and personal selves. At work, everyone was treated as a friend and as a co-worker. However, this was dependent on the individual's comfort levels. As I engaged with the teachers more and I allowed myself to be open by being around during the Tumaini sports Fridays, dancing, learning to speak Kiswahili, I was given a Kenyan name "Kariuki" as a way of acceptance. In my opinion, one of the significant efforts in becoming an insider was my ability to share openly about my cultural identity and allowing them to see the parallels and differences amongst us. This point in my journey with the teachers and the research, when I became an "insider" (a "Kariuki") was crucial as it allowed for co-creation to happen fully and for the teachers to engage fully. During the meso-cycle 3 of the study, one of the teachers' mentioned her ability to feel equal to everyone using my role, breaking the power difference. I think this statement by her summarized my change from an "outsider" to an "insider."

> *Teacher:* "you know in these times, the CoP has given me a lot of experience and it brings me down to earth and I can even talk to you and you have PhD. I only have a degree.
>
> *Dhinesh:* I don't have a PHD yet, but-
>
> *Teacher:* Yeah, you see. And you're pursuing your PhD and we can see the idea. I can tell you something right about anything even tell when you are wrong. It makes me feel like I'm equal to everyone."

As a critical friend, I was able to build stronger relationships, where my position as an outsider was seen without judgments, and my opinions were respected (Elliot, 1991; Ponte, 2002). At the same time, I did the same for the other CoP members, aka teacher participants. Balancing the multiple roles did prove to be challenging. One, the researcher had to be constantly vigilant of the possibility that participants were responding positively simply because they were under study, mainly because of my role as a facilitator (and at times a 'donor' who brings engineering education resources such as electronics, laptops to Tumaini; however, the reality to this perception was that I was purchasing materials for the project from the grant funding) and influence (Hawthorne effect; McKenney et al., 2012). Two, my biases and influence of prior knowledge (before the start of this

DBR study) about the individual participants had to be continuously minimized. The possibility of a Hawthorne effect was mitigated by promoting a climate where the participants were consistently invited to exercise their discretion and express opinions within the critical friends' meetings. Any form of pressure to implement activities without ensuring explicit buy-in was consciously avoided. Collaboration, which is a powerful tool in building participant trust (McKenney et al., 2006), was integral to the design and development process. Signs of partial willingness, lack of ownership, or feelings of pressure surfaced at times during intense collaboration and were resolved through dialogue. For example, during the first meso-cycle, while I continued to operate from the U.S., the teachers felt uncomfortable informing me their confusion in understanding the technical content such as series and parallel electrical circuits. Therefore, they avoided my check-in prompts on WhatsApp, tried to postpone meetings. Once I understood the challenge, I initiated private conversations with each member, and brought them back together upon hearing their feelings individually. Finally, the triangulation of data served to help address any biases I possessed, and so did the data collection activities during the on-going program.

2. BECOMING REFLECTIVE PRACTITIONERS

Radhakrishnan, D.B., Capobianco, B. and DeBoer, J. (in review) Becoming reflective practitioners to build a teaching practice, a community, and an identity as engineering facilitators at an alternative school for "street youth."
Submitted Journal: *Reflective Practice*

2.1 Abstract

This study examined the strategic efforts that untrained teachers situated in a fragile community in Kenya made in becoming reflective practitioners of engineering education. We contend that teachers who lack formal qualifications to teach engineering grapple with identifying effective teaching practices unless they become critically reflective practitioners. In this study, we engaged in critical reflection with three teachers at an alternative school in Western Kenya. The teachers developed effective teaching practices and became self-reliant as well as resilient to the ever-changing demands of the fragile community. Using data from weekly meetings among critical friends, teacher journals, conversations in a messaging app, and supporting documents, this study examined how secondary teachers leveraged reflective practice to transform their teaching and student learning. Analysis of data suggests that the teachers are increasingly becoming aware of their capacity to reflect-in-action and reflect-on-action. Through systematic reflection, the teachers, individually and collectively, showed resilience to challenging and complex experiences with delivering technical content. Results from this study contribute new knowledge on how to support teachers of marginalized youth through reflective practice.

Keywords: reflective practice; design-based research; street youth; alternative school; untrained teachers; engineering

2.2 Introduction

In a special guest editorial for the *Journal of Engineering Education*, Adams and Felder (2008) cautioned that engineering educators are challenged by rapidly changing dynamics of the engineering profession resulting from the increasing power of technology and expanding technical and professional skills demanded by the workplace. After a decade, this challenge persists. To

respond to the evolving nature of the engineering profession, the authors recommended that engineering educators must access a variety of roles, including that of reflective practitioners. In describing the role, the authors stated, 'Engage in collaborative and systematic reflection about what works and what does not (and why) as an essential part of lifelong learning and continuous improvement' (p.239). In 2008, the article responded to the growing challenge of developing engineering educators for new roles that might differ from their training or their experience. Our research study was motivated by a similar but even more complicated question. With the shortage of qualified teachers in developing countries, how can we prepare engineering educators in fragile contexts to equip vulnerable youth with 21st-century skills? Adams and Felder's description of the reflective practitioner's role in engineering education set the foundation for the design of this research study, where "untrained" teachers worked to become reflective practitioners by engaging in collaborative and systematic reflection while implementing an engineering education program. In the following section, I discuss the first meso-cycle of the DBR study using the three stages of Analysis, Design, and Evaluation.

2.2.1 Analysis: Demand for STEM Teachers within Fragile Communities

Realizing the Sustainable Development Goals (SDG) for Sub-Saharan Africa (SSA) hinges on an adequate supply of trained teachers (Junaid & Maka, 2015). Worldwide, over 25% of primary school teachers are untrained, and this phenomenon is increasing in low- and middle-income countries (Global Education Monitoring Report Team, 2013). SSA currently faces a qualified teacher shortage of 17 million (UNESCO, 2016). Studies attribute this to numerous factors (IICBA, 2016; Lambert, 2004), in particular, scarce training programs (Education & International, 2012). The problem is exacerbated in STEM (Science, Technology, Engineering, and Mathematics) content areas; the World Bank explains, "The most important….interventions will be those concerned with equipping…teachers of STEM with knowledge competencies necessary to help learners" (Bethell, 2016. p.3). Studies have shown that untrained teachers lack not only content knowledge, but also pedagogical knowledge and technological knowledge, particularly practices needed for STEM topics such as inquiry learning (Anney & Hume, 2014; Glassman, Naidoo, Wood, Helmore, & O'Gara, 2007). Given the lack of formal teacher training programs to meet these demands, there is a critical need for practical alternative training.

Research on teacher development in engineering is not new. It has evolved rapidly in the past two decades since the national level policy push in the USA for Integrated STEM education in K-12 education (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2007). Several studies of engineering education in pre-college education in the United States have identified related challenges concerning teacher development, including a lack of engineering concepts in teacher preparation programs, attitudinal biases, an existing rigid structure of K-12 (an American expression for kindergarten through 12th grade) curriculum, the complexity of the content area, limited real-world problem-solving experiences, and lack of pedagogical content knowledge (Hynes & Dos Santos, 2007; Nadelson et al., 2013; H.-H. Wang et al., 2011; Zarske et al., 2004). Therefore, professional development for teachers in engineering is required to address these challenges and improve teachers' confidence in their ability to implement an engineering curriculum (Jonassen et al., 2006). However, engineering teaching in K-12 spaces is limited, and its research has situated mainly in the contexts of high-income national settings.

Engineering education is also not typical in informal spaces, for displaced populations, and in contexts of fragility (Author, 2018; Author, 2016). Therefore, researching the development of teachers of engineering in fragile contexts enables us to understand and transfer sustainable skill-enhancing learning programs to low-resource contexts. A decade after the editorial was published, the field of engineering education still lacks relevant and rigorous studies on reflective practice. Despite the sparse research literature, the field has adopted the use of reflection in preparing scholarly engineering educators. The use of reflections to guide actions is increasingly being practiced by engineering educators and are recommended through professional development opportunities both in university and K-12 education (Felder, Brent, & Prince, 2011). Therefore, in order to sustainably support the need for engineering education in fragile, K-12 contexts, effective reflective teacher capacity building programs hold a critical position.

2.3 Research Questions

Motivated by this gap in research and the uniqueness of the context within which we conduct research, the purpose of this study was to examine the different ways three teachers, learning to teach engineering in an alternative school for "street youth" (children who live on/off the street (Steffen, 2012)) in western Kenya, utilize reflective practice to improve understanding of their teaching practice, their students, the discipline of engineering, and the center's teaching

community. In this study, systematic reflection acted as the first step towards encouraging the teachers to become aware of their practices and thereby develop their identity as engineering teachers working in a fragile context. World Vision defines fragile contexts as those *"where government cannot, or will not, fulfil its responsibilities to protect and fulfil the rights of the population, particularly the poor"* (World Vision, 2011). In this research, we adopt this definition to qualify street-youth supported centers as fragile due to the minimal support provided by the government for the population of street-youth and their associated programs. In addition, the center under investigation qualifies as fragile due to its uncertainty in economic and program models, wherein large part it depends on external donor and expert support respectively.

The journey of the three teachers, collaboratively working towards developing necessary skills to teach engineering, provided a unique research opportunity to understand their process. In this study, we examined the following research question:

How does reflective practice heighten the awareness of untrained teachers' knowledge and skills as to their:

(i) practice of teaching,

(ii) teamwork with their community of peers, and

(iii) the discipline of engineering?

The study is part of a three-year-long Design-Based Research (DBR) project started in 2018 to develop a Teacher Professional Development (TPD) model for untrained teachers in fragile contexts. Reflective practice was the first intervention in the teacher development program, where we worked closely with the teachers continuously for three months in 2018, implementing reflective practice strategies. Thematic analysis of multiple data sources revealed the formation of an organic community of practice, where the teachers gained stronger associations with professional knowledge and professional practice as engineering teachers. Based on the results, we argue the need for long-term reflective practice models focusing on fragile communities to provide a detailed perspective of knowledge and skills development of individuals and communities serving a vulnerable population.

2.4 Reflective Practice

Dewey (1938, 1933) suggested that teachers should be encouraged to become thoughtful and reflective professionals, rather than just proficient craftsmen. Since then, many scholars have developed, designed, and analyzed reflective programs and strategies (Greene, 1978; Hullfish & Smith, 1961; LaBoskey, 1992; Liston & Zeichner, 1990, 2013; Schön, 1983; Sparks-Langer & Colton, 1991; Van Manen, 1991). In Dewey's (1938) writings, he asserted that the capacity to reflect is initiated only after recognition of a problem or dilemma and the acceptance of uncertainty. The dissonance created in understanding that a problem exists engages the reflective thinker to become an active inquirer, involved both in the critique of current conclusions and the generation of new hypotheses. According to Dewey (1933), reflective thinking requires continual evaluation of beliefs, assumptions, and hypotheses against existing data, and against other plausible interpretations of the data. To further expand on the notion of reflection, Schön (1983) distinguished between reflection-in-action, or simultaneous with action, and reflection-on-action, looking back on and learning from experience. He posited that it may be too challenging to reflect at the moment given the multiple demands teachers juggle and that reflection often requires a perspective of a 'meta-position'(Schön, 1987).

The need to prepare teachers who will be reflective practitioners has gained wide acceptance, increasingly being adopted as the standard in many countries for professional competence (see, for example, Hatton & Smith, 1995; Jay, 2003; Larrivee, 2000; Osterman & Kottkamp, 2004; Reagan, Case, & Brubacher, 2000; Smyth, 1989; York-Barr, Sommers, Ghere, & Montie, 2005). Reflection in teaching describes practices ranging from analyzing a single aspect of a lesson to considering the ethical, social, and political implications of teaching practice (Cole & Knowles, 2000; Dewey, 1938; Larrivee, 2008b; Liston & Zeichner, 1990, 2013; Schön, 1983). Practice refers to one's repertoire of knowledge, dispositions, skills, and behaviors (Larrivee, 2008). The term reflective practice refers to the on-the-job performance resulting from using a reflective process for daily decision-making and problem-solving (Larrivee, 2008b; Schön, 1983). This wide range of meanings makes it challenging to decipher research findings and has led to attempts to define different types of reflection. Based on their research, Hatton and Smith (1995) suggested that teacher progressions through the levels of reflection appear to be developmental in that teachers may need to reflect first on areas of technical skill before being able to compare different teaching strategies and weigh their relative merit.

Smyth (1989) suggested that even novice teachers can deepen their level of reflection with powerful facilitation and mediation within an emotionally supportive learning climate. There is an emerging consensus that pre-service and novice teachers can be helped to reflect at higher levels with multifaceted and strategically constructed interventions (see, for example, Cole & Knowles, 2000). Journaling, a mediation process, with deliberate prompts and strategically posing non-judgmental questions, has been found to promote higher-order reflection by creating authentic dialogue. Likewise, researchers have found that helping prospective teachers acknowledge, articulate, and challenge their beliefs enhances reflection (Boyd, Boll, Brawner, & Villaume, 1998; Walkington, 2005; Wideen, Mayer-Smith, & Moon, 1998). One form of helping teachers to challenge their world views is recognized via conversations with critical friends. Feldman et al. (2018) describe the role of a critical friend as a crucial factor towards challenging one's world views, deepening reflection, and in the development of a professional learning community or a community of practice. Loughran (2004) characterized critical friendship as a way to "broaden one's perspective on situations in meaningful ways" (p. 158). From this literature, it is evident that for teachers to be empowered, informed-decision makers, reflective practice plays a crucial role, and targeted, intentional, and meaningful facilitation through various strategies can enhance one's growth as a reflective practitioner.

2.5 Status of the LED program during Meso-cycle 1

During the design and implementation of meso-cycle 1, the first version of the Localized Engineering in Displacement was on-going. The final classes of technical content were being taught that included the topics of solar PV load calculation, system design, circuiting, series, and parallel circuits, followed by prototyping, communication, and system installation. The content for each of these classes was prepared by our lab and loaded on to the Qdex platform for the teachers and students to access via tablets. During the progress of the class sessions, the teachers mainly found the topic of series and parallel circuits challenging. In addition to online resources, I prepared short class sessions of each 10 minutes on the issues the teachers found challenging and communicated via our WhatsApp group (figure 10). The teachers used the videos to gather further knowledge on the topic and delivered them to the students.

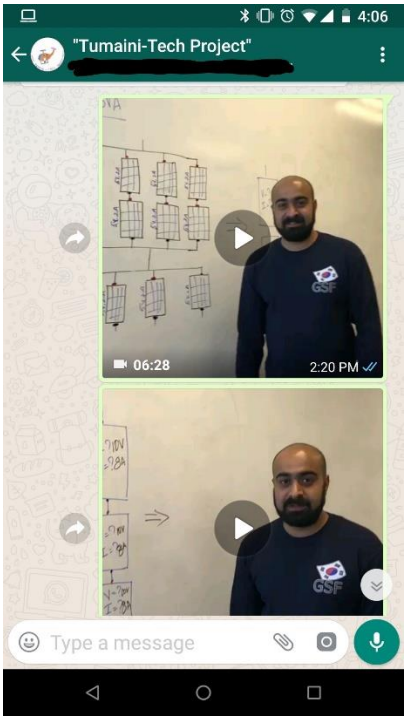

Figure 10. Short online lessons on LED content created as teacher support materials and transferred using WhatsApp group

By the end of March 2018, the students tested the prototype, made improvements to the final design, and completed the installation of a solar PV system to supply power to the lighting loads in Tumaini. The teachers and communicated their final design, approach, and the project to Tumaini's community, partners, and stakeholders in May 2019.

2.6 Design: Meso-cycle 1 of DBR and Data Collection

The study began with a 6-hour kick-off workshop in February 2018. The kick-off workshop assisted in the formation of a collaborative team, goals, and expectations (Figure 10), guidelines, and the central theme for this collaborative group. The teachers and I collaboratively first brainstormed the existing challenges in delivering the LED program to the students. Following the discussion on challenges, the team realized they needed to establish the structure for the collaborative community. We further brainstormed on the goals and expectations of individuals and as a team and design guidelines for the group. We used the techniques of developing guidelines, and central theme based on the recommendations from *Teachers Investigate Their Work* (Feldman et al., 2018).

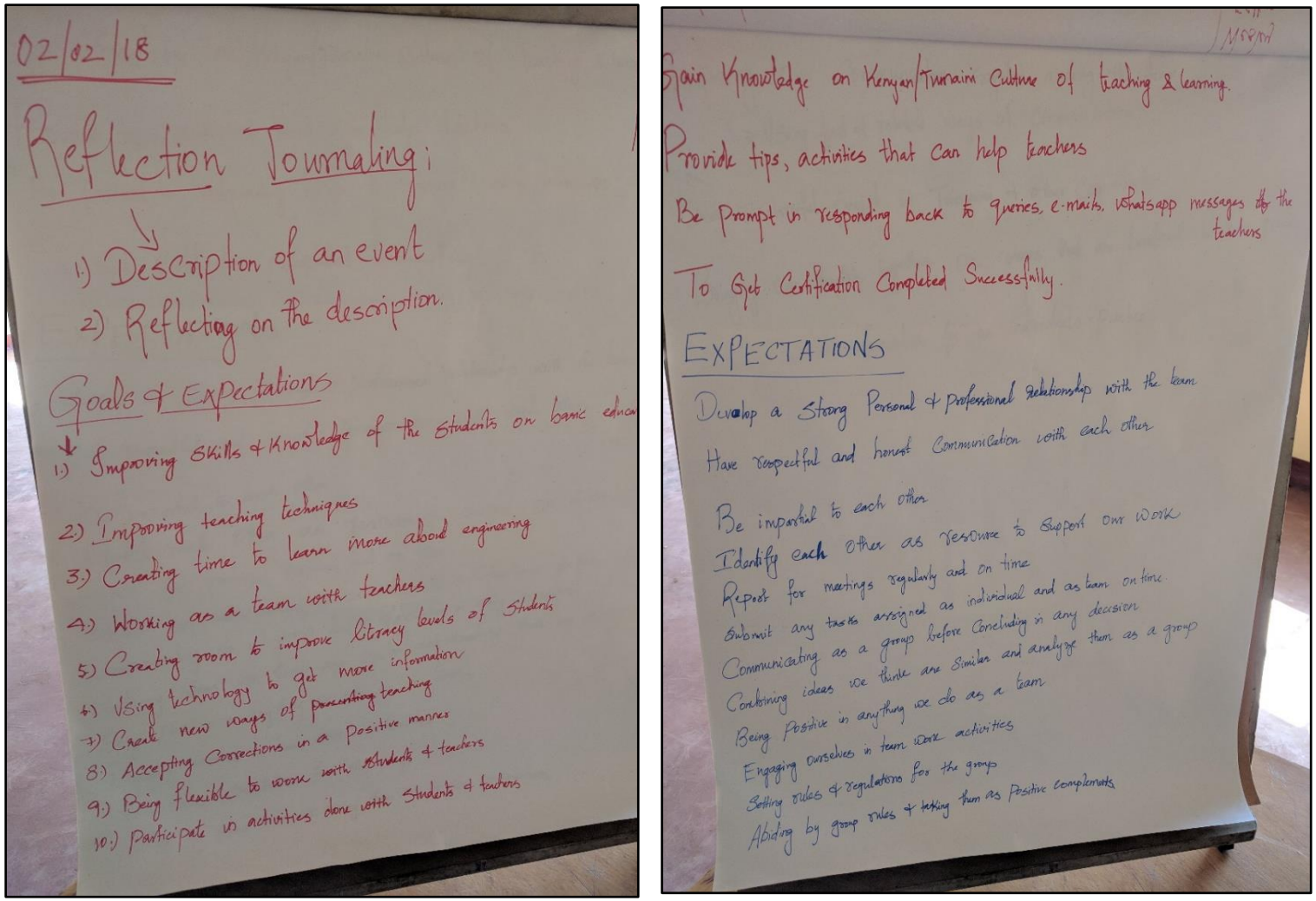

Figure 11. Goals and expectations for the collaborative community of teachers and research brainstormed during the first group meeting in February 2018

I further introduced the teachers to the model of reflective practice (as presented by Larrivee, 2000), and we discussed potential strategies to enact reflective practice relevant to the context. The artifacts produced from these workshops served as guidelines, although this was not an instrument for data collection. The techniques of journaling, critical friends' meetings, classroom observations, and feedback were used during the three months to enable reflective practice. They became the data sources for our investigation (See Figure 12). This variety of data collection sources allowed us to gather extensive qualitative data and provide opportunities for guided and unguided reflection.

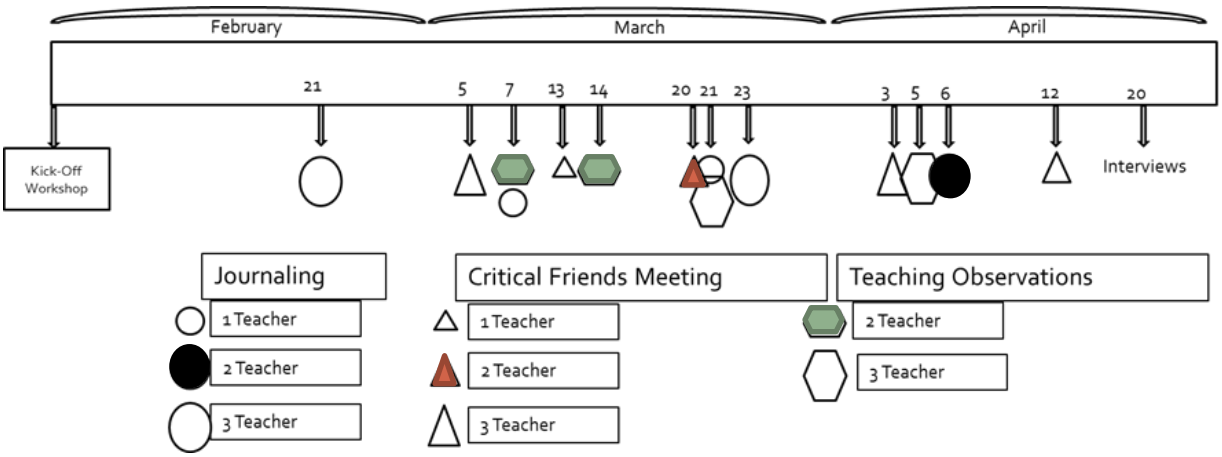

Figure 12. Timeline of reflective practice strategies adopted by teachers during meso-cycle 1

2.6.1 Journals

Journals (in physical notebooks) were intended to provoke reflection on the teachers' experiences before, during, after class sessions. The teachers requested I share examples of a journal for reference. I shared the examples from Hinchey's (2008) action research book and a journal I prepared for a class I taught (Appendix F.). The teachers used the double-entry (Feldman et al., 2013, pp.24) format of reflection for their pre- and post-class reflections. A total of 4 journal entries were completed by each teacher for a total of 12 journal entries. For the last scheduled journal entry, the first author prompted the teachers to discuss their learning, surprises, and challenges in teaching engineering.

2.6.2 Critical Friends Meeting

Critical friends' meetings included the meeting of the three teachers and me. We participated in five crucial meetings weekly where we debriefed about the teachers' weekly journal responses, engaged in detailed conversations about individual teacher experiences in the class, and planned for subsequent weeks. This allowed the chance to explore further and understand each teacher's decision-making and associated classroom challenges.

2.6.3 WhatsApp Conversations

WhatsApp, a texting app, was used to serve as a flexible, real-time platform for continuous engagement and virtual collaboration. A group was formed in the app to allow the teachers and (first author) to communicate virtually throughout the study.

2.6.4 Interviews

Individual semi-structured interviews (45 minutes in length) were conducted with the three teachers after the final week of the program. The interviews gathered more information about the teachers' experiences with teaching engineering, their experiences with building a CoP, and their insight into learning from their reflections.

2.6.5 Member Checking

Upon completion of the first round of analysis, emerging findings were shared with teachers for member checking. An online group call was organized to discuss the teachers' perception and interpretation of the results. The audio recording of the call was further transcribed and used as a data source in the final round of analysis.

2.7 Data Analysis

Data were analyzed using thematic analysis. Braun and Clarke (2006) define thematic analysis as "a method for identifying, analyzing, and reporting patterns (themes) within data" (p. 79). At each stage of analysis, the data were coded using the following process. First, in the process of "open coding," a code was assigned to a unit of analysis defined as a word, phrase, or sentence

(Saldaña, 2015). For example, when teachers discussed the practices and frameworks around teaching, these statements were coded as "TCHN PRAC" or "teaching practice." Another example was that when the teachers described events when collaborating with one another, these events were coded as "PEER COLLAB" or "peer collaboration." We then read, re-read, and grouped these codes into common categories using the following four aspects: "meaning," "practice," "community," and "identity," the components that Wenger (1998) describes as necessary to characterize social participation as a process of learning. We later merged these categories to form patterns or trends in the data. These trends were confirmed across multiple data sources. To enhance the generalizability of these findings (Huberman & Miles, 2002; Yvonna S Lincoln & Guba, 1985), we conducted member checks of vignettes of the teachers' responses and later refined these interpretations based on the teachers' feedback.

2.8 Integrating action research

In order to integrate reflective practice in this community, the teachers and the researcher followed three key strategies.

1.) Formulating a central theme for the group
2.) Establishing regular meeting expectations, and
3.) Providing multiple means of communication (face-to-face, and virtual)

2.8.1 Central Theme

As mentioned in the data collection, the first kick-off workshop was used to formulate and establish a central theme. The central theme was identified as a strategy to allow equality of interest for every participant while also as a group (Capobianco, 2002). The central theme for the group was identified as *"Improvement in practice."* The improvement in practice was valued both from an individual perspective and as a group. For example, Ellie wanted to improve her practice in engineering both as an engineering teacher and learner, while the whole group wanted to improve its practice in designing and operationalizing the engineering program in the school. The central theme served as a guide during all the conversations, reflections, and action steps to check and evaluate if the input and output are focused towards improvement in practice.

2.8.2 Regular meetings

To ensure consistency regarding continuing the cycle of action research, we established regular meeting expectations. Participatory design of systems and structures was identified during the first kick-off workshop and was implemented throughout the program. This included fixing regular meetings, planning the logistics, and devising a clear agenda for each meeting. We agreed to have a weekly one-hour call for five weeks. These meetings served as the critical friends meeting and allowed us to engage in dialogues that facilitated progress towards the established goal.

2.8.3 Means of communication

Our third strategy was to provide multiple means of communication that allowed for rich and timely discussions. The teachers met face-to-face multiple times during the week and had both informal and formal conversations regarding the course, the project, and developments. They often shared with each other the status and developments from each of their teachings and also gained support from each other. The teachers and researcher communicated daily through WhatsApp group and sometimes through individual chats in the group where the teachers updated on the events, shared photographs of their sessions, and discussed them.

2.9 Evaluation: Findings

The data analysis resulted in two major themes. The themes generated explain how reflective practice played a role in heightening the awareness of teachers' knowledge on the practice of teachers, their community of peers, and the discipline of engineering using the theoretical lens of situated learning and communities of practice.

2.9.1 Theme 1: Reflective Practice Enabled Mutual Engagement of the Teachers

Mutual engagement is the characteristic of practice that is the source of coherence of a community (Wenger, 1998). A community exists because people are engaged in actions whose meanings, they negotiate with one another, and as a result of those actions, practice prevails, and grows. Wenger (1998) discusses that mutual engagement "involves not only our competence but also the competence of others. It draws on what we do and what we know, as well as on our ability to connect meaningfully to what we do not do and what we do not know – that is, to the

contributions and knowledge of others" (pp.76). For the teacher participants in this study, adopting reflective practice allowed them to recognize their own and other's competencies as essential and as a source of knowledge for the practice of teaching engineering. As they began to work as a team and participate in this design-based teacher development program, they recognized each other's expertise, connected meaningfully, took actions to improve teaching practice, and therefore established mutual engagement. According to Sandra, Ellie's professional teaching experience and knowledge were crucial for Sandra's own learning to teach and continue to develop an identity as a teacher.

> I have learned teaching. Being a teacher. Ellie being a teacher has ... and seeing how she teaches has really encouraged me to learn a few things from her about being a teacher, and how to get the boys to participate in class, and how to get them to remember some of the things. She's actually a really good teacher. She's actually a professional teacher, unlike some of us for who this is the first time we are doing this…. I have seen her and learned being a teacher. (Sandra, Interview)

At the same time, Sandra also recognized the opportunity to share her competencies that were critical for continuing the practice in this community when Ellie was able to share her challenges with teaching math content. Sandra believed she would be able to support Ellie given her background in economics and familiarity with calculations. During the critical friends' meeting, Sandra shared:

> Sandra: When I was even having a talk yesterday with Ellie, she was saying that she's having a hard time with the mathematics module.
> Author 1: What part, like what kind of challenges?
> Sandra: Basically, she said anything that has to do with math. The module is giving her a hard time. But she just brought up the topic. We were just talking and then she said, "By the way, I'm having a hard time with the calculations in the module." At that moment, I didn't do anything about it but it's something that I want to do. I plan to help Ellie with the calculations. I am more comfortable with it. I like Math and have taught it before. (Sandra, Critical Friends Meeting 3)

Ellie recognized Sandra's competence with mathematics and leveraged Sandra's expertise to address this challenge in her practice. Ellie initially struggled with admitting having difficulty with the math content. However, upon recognizing that her peers could help, Ellie admitted her challenge. Ellie opening up about her challenges, was a crucial part of the development of the teachers' community, the mutual engagement, and the role of reflective practice, as the vulnerability allowed each other to respect each other mutually and reflect on their role as engineering teachers. During one of the critical friends' meetings, she said:

> Something that I choose to ignore… in some of the chats in the (WhatsApp) group because if I didn't participate on anything, then I wouldn't be given any tasks on calculation. But later, I must admit that by attending the classes that Sandra took us through, I can now handle the calculation class. It was very beneficial for me and I learned a lot. (Ellie, Critical Friends Meeting 4)

For Sandra, recognition of her competence with teaching math helped her feel that she belonged in this community. Here, Sandra demonstrated engagement and membership in the community's practice and in the community itself, because being included in situations that matter is a requirement for being engaged (Wenger, McDermott, & Snyder, 2002). During the interview, she stated:

> ……getting to a point where she (Ellie) was saying that now she's comfortable enough to teach math. Because before, she used to tell me, "There is math in my module class. I am not comfortable in teaching that." But now she says, "There's math, and I think I can do this, but I will need you to help me with one or two things." For me, it was a great success. It is getting to help the other teachers with the math in the modules, and also giving them a chance to know that everyone at every point can learn and actually understand some of the concepts that you are teaching and teach others. (Sandra, Interview)

At the start of the engineering program, the teachers held various assumptions about their roles and individual capabilities to be part of this project. They questioned their abilities and qualifications to be part of this engineering program. William, who has been in the program the longest, reflected during his interview the challenges he faced initially, and how they overcome the challenges upon realizing the strength in doing things together with other teachers.

> Since we started when the other two, Sandra and Ellie were not there, when we were with Jack (the first instructor), we were really a bit reluctant. Because, that time we didn't understand how we can teach engineering and what it might yield. So, we were really a bit reluctant. Then, when Sandra and Ellie came together, we thought we will do it. But Ellie was the only teacher. Since then from last year, when we came together the journey of this engineering class has become very lively. Because, we came to know each of us can help other. We knew something, the other did not, and we were ok with it and learned from the other. (William, Interview)

Wenger (1998) highlights that mutual engagement in a CoP is similar to any real-life mutual relations, which experience both conducive and challenging situations, feelings, and environment. In our study, as well, the teachers discussed situations that were challenging and ways the challenges were overcome through reflective practice. Observation of classes, one of the reflective practice activities that were initially recommended to the teachers, was contested and associated with discomfort. Sandra reported,

> …about the observation, it was a bit…. You're really not yourself at that moment because, you know, someone is observing. I felt as if it is not as successful as would have been expected. (Sandra, Critical Friends Meeting 3)

Here, Sandra specifically mentions the other teachers as "someone is observing." Since the three teachers did not collaborate in a teaching environment before this program, they were perceived as outsiders in each other's classes. Such discomforts were overcome when the skills of a fellow teacher were recognized, and the diversity was appreciated. In this case, Ellie's reflection on her training as a teacher allowed her to share her knowledge, thereby initiating a change in perception towards observations.

> I'm trained to teach even in front of my director, and to teach in front of anyone. For Sandra, it was a little bit shy for her, for me to join her class. I felt she was uncomfortable. But then I just had to attend it, and I found it more interesting, because I learned a new model of teaching, I learnt new skills, I learnt new things from how they approach everything. And they also learned a lot from me. I could give them tips that they never had about teaching. They gave me tips that we should introduce into the teaching culture, and it became very productive. (Ellie, Interview)

Sandra conveyed how the challenge changed into a benefit during the final interview:

> Having a teacher also in class also helped, because the ... It seemed easy having someone else who understands what you're saying being in the same room before explaining it to others. So, if, for example, I had an issue with translating something, and I know Ellie is there, and Ellie is a Swahili teacher, then she was able to help me convey that message to them in a way that they understood. When we did it, it was really awesome for me. (Sandra, Interview)

Teaching engineering was unfamiliar territory for all three teacher participants. As they developed an interest and assumed the role of engineering teachers, they needed regular peer support. Reflective practice rightfully served as a start, whereby they created opportunities to recognize individual competencies; established a platform to form an active community where they could share and learn from each other; and developed a safe environment where they could be vulnerable with one another. Using reflective practice allowed the teachers in this study to establish a community, where they see each other as resources to rely on and function effectively.

2.9.2 Theme 2: Reflective Practice Enabled Identity to be Shaped and Re-shaped

As the teachers engaged in the engineering program and began adopting the reflective practice, three forms of identity evolved, each at various stages of development. They are identities

as (i) participants of the engineering teacher community of practice, (ii) engineering teachers, and (iii) engineers.

Participant in a CoP – Identity of a Fully Formed Membership

Wenger (1998) notes that practice defines a community through the dimensions of mutual engagement, joint enterprise, and the negotiability of a shared repertoire. These three dimensions reify an individual's membership in the CoP, thus developing an identity on the spectrum of full vs. peripheral membership. Each dimension as it solidifies enables the participants to navigate from a peripheral to a full membership in the CoP. In theme 1, we have extensively discussed how reflective practice has helped in the formation of one of these dimensions (mutual engagement). In our study, the teachers, by recognizing their own and other competencies, engage in a mutually beneficial relationship. However, in this second theme we briefly describe the role of mutual engagement with respect to identity development, where the teachers' demonstrate membership in the community by sharing their strengths. The individual's competence gains value as it becomes acknowledged and shared. This translates into a form of individuality that is being defined with respect to the teachers' community (Wenger, 1998). In this case, as members of the CoP, teachers consider it vital for them to give and receive help more than to know everything by themselves. William highlighted this:

> …. we've, our team has come along well, especially after you (author 1) came and introduced us about the journaling and about reflective practice. We are having a conversation together, the three of us between me, Sandra, and Ellie. So, I was helping Sandra on a project. if I'm having difficulty in other areas, Sandra will help me. So, if I am having a problem, or others having a problem, we will solve it together. So, if you are not having that team it would have not worked better. (William, Interview)

For Sandra, sustained engagement meant helping each other overcome their limitations. She identified that by scaffolding the challenging content in a way the other teachers can understand, it allows for development.

> Involving William in the last class that I did with the question, the question that you (author 1) sent us for the ... What it's called? Calculating the voltage, current and the total power, it was a really good thing that ... You can actually empower someone to do something that they didn't believe in doing it by themselves. By actually first showing them, and getting them also to understand, then allowing them now to teach others. Once I was able to show that to William, he knew it, taught the students, and also Ellie when she had problems. (Sandra, Critical Friends Meeting 3)

Wenger (1998) notes that, once the three dimensions are established, this results in full membership, or the meaningful engagement of the teachers in full capacity to sustain practice. Teachers in this context find the center's community to be a familiar territory where conversations, activities, and involvement become natural and accepted. As the teachers invested themselves in the enterprise of developing their skills to teach engineering at the center, they developed an identity of accountability through which they were able to contribute to the CoP and thereby the enterprise itself. As an identity, this accountability manifests as a tendency to come up with interpretations, engage in actions, make choices, and value experiences (Wenger, 1998). During the final interview, Ellie confirmed that observations that were introduced as a reflective practice strategy to observe each other's teaching helped develop essential skills. In the end, the observations eventually became an integral part of their teaching practice and being accountable to the enterprise of developing the engineering teacher community at the center.

> Yeah. In fact, after that class, the observation class, we have been attending the classes more frequent, like three of us, without even you (author 1) planning for it, because we noticed that through that, we are able to shape each other, through that you can be able to rectify each other in a positive way, and through that, I can learn something that I may approach in the next class and I didn't have an idea of. From then we have made it a regular thing that to teach the next class, you need to attend the other teacher's class first. (Ellie, Interview)

Continuous engagement in reflective practice yielded the ability for the teachers to interpret and make use of the artifacts and other repertoires of that practice. Actions and artifacts such as the critical friend's group, journals, and others became internalized and the language of the community. Wenger (1998) calls this the personal history of participation, where, as an identity, this translates into a "personal set of events, references, memories, and experiences that create individual relations of negotiability for the repertoire of practice" (pp.153). Ellie discussed,

> It is an achievement, and especially with the group that we created, the WhatsApp group, and the journaling. I never imagined I can do journaling that can guide me to do classes. So, it has been so productive for the past two months, because each time that I get to do something that I don't understand, I just go back to anything that I've written down, anything that we've discussed in the group, and it gives me guidance. (Ellie, Interview)

The growth across these three dimensions of a community (mutual engagement, joint enterprise, and shared repertoire) has allowed the teachers to encounter new practices and venture comfortably and sustainably into the unfamiliar territory of teaching engineering. However, the recognition of competencies, understanding the enterprise to which they are accountable, and

sharing of the resources they developed and used to communicate helped the teachers more fully solidify their membership in this evolving CoP.

Engineering Teacher – Identity Existing in a Learning Trajectory

Identity is not an object but a constant state of becoming (Wenger, 1998). In our study, particularly the teachers' identity as an engineering teacher, is a construct that is on a constantly negotiated learning trajectory. When the teachers started as engineering teachers, their learning trajectories were unclear. However, the teachers negotiated their identity as engineering teachers themselves since they began reflective practice. The teachers demonstrated convergent trajectories (Wenger, 1998) when they faced focused challenges, participated in the community, and adopted the reflective practice, which allowed them to develop beliefs and take action to overcome them. For example, Ellie's identity as an engineering teacher took shape when her reservations with teaching math calculations were resolved upon critical self-reflection and participating in the community. During the interview, she stated:

> I have learnt that calculation is something that I can also handle, it's just a matter of mentality. I have learnt that I can teach calculations. And I've also learnt it is okay to be wrong. It is very okay to be wrong. When I don't understand anything, it is okay, and I should ask for answers and don't feel embarrassed. Because Sandra helped, I am confident now. When I could teach those calculations, I knew I can teach anything in Engineering. It was the worst fear, so now I know to handle anything. (Ellie, Interview)

The converging trajectories were again demonstrated when the teachers built specific knowledge, skills, and attitudes as a means of the practice. Sandra's reflections illustrated that her engineering teacher identity is in constant negotiation with the understanding of the field of engineering. In her work journal, she discussed:

> Preparing for the classes always puts me in a position of learning how to unlearn somethings (myths about engineering). How to learn new things and also continue learning more and due to this I have learned three things about engineering. Teaching engineering is not based on assumptions of what you might know but rather on facts that are proven, theoretical and practical teaching of engineering go hand in hand, teaching engineering goes both ways (i.e.) both students and teachers teach each other at some level. (Sandra, Journal 4)

However, the teacher's responses showed divergent learning trajectories when they started to define the role and qualities of an engineering teacher themselves. By divergent, we mean the natural ways of encompassing learning from their other identities (such as a teacher, economist,

social worker) and linking their past and present experiences to scope future roles. For Ellie, an engineering teacher must be dedicated, cooperative, and vulnerable to learning and change.

> I think a good engineering teacher needs to be focused. A good engineering teacher needs to be ready to accept correction. A good engineering teacher should be ready to encounter new things, new adventures, new things on his or her teaching. Like how I encountered calculation and found them easy. I think a good engineering teacher should learn how to associate with the students, cooperate with the students and the co-workers, and also be ready to consult anything that he or she doesn't know about. That would make him better every day. (Ellie, Interview)

With this understanding, Ellie wants to step forward and continue to grow as an engineering teacher. During her final presentation, she discussed her desire to design her engineering courses.

> Yeah, and even designing our own, our own course. Because, engineers solve problems, that what we have had (learned). And I believe we can solve our own problems by designing our own course. I am looking forward in the future to be the one designing the engineering courses at the center. (Ellie, presentation)

It can be understood that the engineering identity development process started well before the intervention of reflective practice. However, as they began to practice reflection, identity development strengthened. For William, an engineering teacher must be flexible in adapting to teach both hands-on and theoretical content, while also being open to having new learning experiences.

> One must be very flexible. Amount of flexibility. Before entering a class, an engineering teacher must be, you have to be flexible, because when you're teaching engineering there is the side of practical, and the side of theory. So, as a teacher you have to be…for example let's say practical. In practical you need to know and experience practical. So, one must be flexible to face any challenge. Yeah, because the journey has been long, I have learnt to be flexible, because I have managed between field work, doing classes and being strong. (William, Interview)

Post reflective practice, for the engineering teachers, being on this learning trajectory is important. They have developed an understanding that improvement in their performance will mean advancement, and it has reified their need to participate as an engineering teacher in their community. For teachers, teaching engineering is not just a job task. As the quotes above show, each action is an event on a trajectory through which meaning is negotiated and identity is formed (Wenger et al., 2002).

Engineer – Forming Creative Social Bridges

The three teachers, in addition to this engineering community of practice, by nature, belong to many other communities of practice based on their educational background, professional qualifications, job roles, personal affiliations, and more. Their membership in these other communities range from full to peripheral participation. Whatever the nature of their participation was, these other memberships contributed to their engineering identity development. In this study, it was evident from the teachers' statements across the data sources that their engineering identity was forming in the nexus of this multi-membership.

For Sandra, acquiring the skills of an engineer added strength to her portfolio, while it also allowed her to perform her other roles effectively.

> When we're talking about teaching or engineering, I am not a teacher or an engineer by profession. I'm an economist, William is a social worker. For me to have other skills and to know that maybe I can be able to connect with my goals, for me, it gives an advantage and even gives me more morale to do more. So, it's not only about teaching and how we've been teaching and everything, but also as teachers, are we getting skills or are we teaching something without knowing it. For example, we were brought a solar panel here, would we be able to identify the parts of the solar system or handle the whole solar panel system. It's something of that sort. That's why I'm saying, involving the teachers in also having their own projects apart from the ones that the boys are doing will be motivating. (Sandra, Critical Friends Meeting 3)

Given the opportunity, Sandra transferred the knowledge of the engineering design process to her other work responsibilities. This act of transferring the knowledge and skills across their membership activities reflected their identities as engineers forming social bridges across their professional and personal practices.

> …the engineering design process that we have been talking about here, I have been actually been able to implement that in other areas in the center and for my own life. Like to design some management structures that we are coming up with, we have been able to use the same design. I find a problem at home and apply this to better understand and solve it. So, for me it is not just teaching engineering, being an engineering teacher but also being able to take what we are learning in engineering and transferring it in other things and teaching others the same design and coming up with structures and systems that can actually work. (Sandra, Final Presentation)

Through this application of learning, Sandra began to take notice of her identity development. During member checking, Sandra stated:

> I think you (author 1) have brought out some of the aspects we show about it but not entirely, not as it is in reality because we find that engineering, we simply cannot say we

> are all engineers. But right now, we can say we are an engineer. But you see we had to go through the trainings, the workshop and getting to understand simple engineering that we are doing at the center, but the perception about engineering as a whole it has … People who are called to be engineers …Who are trained to be, well, and so it's not something that anyone can just do. Here in Kenya, you need to go to university for five years and only those people are engineers. And for us getting to a point where an economist, a teacher and a social worker are teaching engineering things, that's a really huge step. (Sandra, Member checking call)

These perceptions are a result of Sandra's participation in other communities of practice during her education and from her friend's circle. Sandra and Ellie discussed the gender bias in the engineering field and that they experienced prejudice during discussions but could demonstrate their strong association with engineering.

> …..it may not seem like a big actual change at the center mainly because we are not only teaching engineering but also other subjects, but mainly on the issue of engineering I think it's important, for example, I was talking to Stella (Pseudonym of Sandra's friend and an engineering student at local university) and she said there are only six engineers who are women in her class maybe. And the class is like 60 or something. When we get visitors (at the center) we can talk about this engineering part, but I don't know if others get these questions most of the time but people asking me, "You teach simple engineering?" We do. Yes, and what is that, simple engineering? And if I explain, it's something that we see this change in their perception that there is also women in engineering field. It's still a new thing for the people. But if you might like also talking to the visitors about the basic education, you get like it's just flowing, but when you mention just simple engineering and you mention about solar panels and you mention about all the other things as they are like, "Oh, how did YOU do that?" The good thing that they ask but also in their questions you get the intention of the question is, "How are YOU able to do that?" That is a field that is done by men so it's something that should be pointed out that we do too. (Sandra and Ellie, Member Checking)

Transferring the engineer's role and knowledge to their other practice and confronting public attitudes and perceptions that surfaced through other memberships, has developed new meanings for the teachers in this study. Consequently, the teachers negotiated their activities and identities, and at the same time, the history of relations among their communities of practice (Wenger, 1998).

2.10 Reflections: Discussion

Sandra, Ellie, and William shared the same conditions of working, and that became a central factor in defining the enterprise they engaged in (engineering teaching and learning). The collective construction of this local practice made it possible for the CoP group to form and demonstrate a willingness to participate in the development process. From this research study, we

have identified that reflective practice became the foundation and a contributing factor for the collective construction of a long-term engineering teacher development model via Communities of Practice. Journaling, observations, WhatsApp chats, and critical friends meeting records have become the artifacts, actions, and language in this community through which participation was facilitated and practice was sustained. Reflective practice played three critical roles in this design-based teacher development: (i) enabled mutual engagement, whereby teachers developed recognition of their own and others' competencies and found meaning on their practice through collaboration; (ii) served as the platform for negotiation of their identity development as community members, engineering teachers, and engineers, and (iii) led to the establishment of a fully formed community of practice (Figure 13)

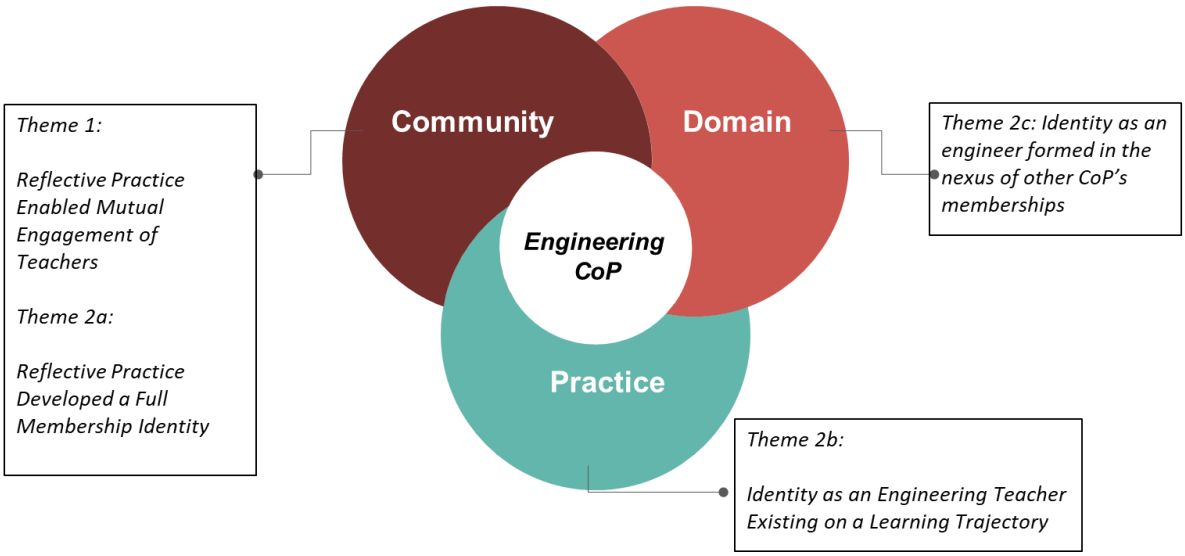

Figure 13. Research outcomes from meso-cycle 1 based on the three inter-related elements of a CoP for the design solution implemented

All three teachers used reflective practice strategies to critically think about their own roles and development. While Sandra and Ellie developed important senses of meaning around their own capabilities and responsibilities, William developed a deeper understanding of teamwork and membership in a community. This interpretation must be understood alongside the fact that reflective practice is a continuous development activity amongst these teachers, and they used it

to continue to negotiate meanings and develop identities. Therefore, the results from this study are on a longer continuum of development in the CoP and not a final evaluation of the teachers' development. According to Koliba and Gajda (2009), a CoP "engages in varying degrees of person-to-person communication, decision making, interdependent actions, and reflection on the efficacy of those actions in order to change practice and improve performance" (pp. 30). Engaging in collaborative reflective practice aimed at improving engineering teaching has naturally led to the formation of a CoP in this study. According to Wenger (1998), the social theory of learning includes four components: learning as experience (meaning), learning as doing (practice), learning as belonging (community), and learning as identity (becoming). These components are interconnected and mutually defining (Wenger, 1998). Based on our results, we contend that these components are nested within each other in the context of our study.

Encouraging teachers to critically reflect within a CoP helped the teachers in this study challenge assumptions, develop new knowledge, and address issues specific to fragile environments (Ng & Tan, 2009; Tan, 2008). Results from this study suggest that the teachers identified key benefits of engaging in reflective practice individually and collectively. From improving their understanding of the engineering content to enhancing their perspective of their students as learners, teachers in the study found reflective practice as an effective tool for learning to teach engineering and developing an engineering identity. Deliberately structuring critical reflection in teacher communities empowers them to go beyond sensemaking to reflect on issues that are general and contextual so as to maintain a broad vision about their work and not just look inwardly at their own practices (Liston & Zeichner, 2013).

2.11 Conclusion and Implications

Reflective practice was foundational to this emerging community of practice. The sheer act of joining together, sharing concerns, generating action strategies, and make meaning of these actions, allowed the teachers in this study to establish a reflective CoP. This CoP, in turn, has allowed teachers to develop and enhance their engineering practice. In this study, teachers collaboratively utilized reflective practice as a tool to leverage their current educational situations not only to improve their practice but the community as a whole.

Reflective practice has made their relationship with one another and their own practice more meaningful. By working together, teachers strengthened their existence as a group of reflective

practitioners, resulting in new way of teaching engineering in a fragile school community. It has allowed them to recognize their own and other's competencies as vital sources of knowledge and resources. Reflective practice has eased them into an unfamiliar territory of teaching engineering and to begin developing deep cultural, and contextual understanding in relation to the practice they wanted to sustain. Lastly, engaging in reflective practice has allowed the teachers to add reflective practitioners of engineering education to their professional identity in addition to social worker, economist, and teacher. Adding credibility via a programmatic outcome such as a certification to the efforts of these teachers in this informal training is crucial as the teachers clearly identified the differences as an engineering teacher in formal vs. an informal environment. Therefore, after the completion of this research study training modules were registered as a curriculum on "reflective practice in engineering teaching" at the Author's institution that earned the teachers a certification and continuing education units.

Implications from the study suggest that reflective practice is a powerful mechanism that empowers teachers within a fragile community to actualize their teaching and learning of content, pedagogy, and students. Reflective practice may also merit opportunities for teachers to deconstruct and re-construct their understanding of teaching a new discipline, make meaning of how best to meet the needs of students at risk, and build a growing and prosperous community of practitioners. This study has built the foundations of a longer-term collaboration with the alternative school through the establishment of the CoP. As a next step in this design-based research, to advance their understanding on their teaching and provide tools for continuous improvement, we are working together within the CoP to establish a collaborative teacher action research group with each teacher investigating their problems of interest. These efforts will inform a model for strategic teacher development to enable teachers without engineering content background in fragile communities to become critically reflective and evidence-based engineering instructors.

3. ENGINEERING TEACHERS BECOMING ACTION RESEARCHERS

Radhakrishnan, D.B., Kimani, S., Wairimu, E., Kimutai, W., Kimani, S. and DeBoer, J. (in preparation) Engineering teachers becoming action researchers through a community of practice at an alternative school for "street youth" in western Kenya.
Targeted Journal: *Educational Action Research*

3.1 Abstract

Estimates of "street youth" (SY, children who work/sleep on the streets) in Kenya are over 45,000. Engineering education presents a unique opportunity to realize the potential of this population to develop 21st Century skills. However, teachers at alternative schools for "street youth" are untrained in STEM education, and the issue is exacerbated by the shortage of qualified teachers in sub-Saharan Africa. We have pioneered an approach in preparing teachers to facilitate engineering programs at an alternative school for SY in Kenya via an engineering Community of Practice (CoP). In this design-based research study, the teachers use action research to improve their teaching of engineering, the building of a stronger community of peer teachers, and the learning associated with conducting research. Results indicated that by adopting action research, the teachers developed new pedagogical content knowledge, provided meaningful learning to students, became vulnerable amongst critical friends, and transferred knowledge of engineering and research to other practices. Results from this study contribute new knowledge on how to support teachers of marginalized youth through action research.

Keywords: action research; design-based research; alternative school; untrained teachers; engineering

3.2 Introduction

Sandra, Ellie, and William (pseudonyms) are three untrained engineering teachers at an alternative school for "street youth" (defined here as children who work/sleep on the streets) in Western Kenya who advocate for their students and facilitate introductory engineering courses. Untrained teachers are individuals with no or limited qualifications and training in teaching. Generally they are appointed on official capacity as teachers or as volunteer teachers by

government, organizations, and institutions to teach students on assigned subjects in an educational environment (Kunje & Stuart, 1999). They are recruited to meet the ever-expanding educational needs of the nation and because they need work (Kunje & Stuart, 1999).

The alternative school, initially started as a drop-in center for street children, transformed into an innovation center hosting SY in primary and vocational education. The primary education teachers in this study, who formed the majority of the teaching staff until the end of 2018, had limited or no experience in teaching Science, Technology, Engineering, and Mathematics (STEM) subjects. Having taken part in the co-facilitation of the inaugural engineering-based curriculum, the teachers reported that engineering plays a significant role in the development of skilled citizens, and they were interested in learning more. The curriculum was designed and delivered by engineering education researchers from a large midwestern university in the United States. The researchers, in collaboration with the teachers, started a design-based approach for long-term professional development to facilitate the engineering program at the center. The teachers initially took part in professional development opportunities that used the model of reflective practice, which then organically resulted in the formation of a Community of Practice (CoP).

In this study, we present how the untrained teachers learned to engage in action research. While becoming reflective practitioners, the teachers developed stronger relationships with their teaching practice, their peers, and the discipline of engineering. Upon identifying these relationships, we hypothesized that training teachers could strengthen them as researchers. Action research studies have shown that the ability to research in respective teaching environments leads to continuous development in self-understanding of the practice, the discipline, and the "own-selves," which is critical to sustaining meaningful development efforts (Goodnough, 2010). In this study, we investigate action research influenced a teacher community-of-practice, and identify the changing relationship of teachers with their practice, peers, and discipline.

3.3 Research Questions

There is an emerging consensus that preservice and novice teachers can be helped to reflect at higher levels with multifaceted and strategically constructed interventions (see, for example, Cole & Knowles, 2000). In 2018, at the alternative school, design-based research was initiated to design a continuing professional development model using the framework of reflective practice. The three participating teachers used reflections to plan, act, and observe their class sessions. By

engaging in reflective practice over three months, the teachers learned to function as a collaborative team, improved their teaching practice, made meaning of their engagement, and started the construction of their engineering teacher identity. Consequently, this resulted in the formation of a Community of Practice through ways of mutual engagement and developed an identity of membership in the community. As the next step in professional development, the teachers and researchers agreed that developing their skills as researchers could strengthen their role as engineering teachers.

In this study, the teachers used action research to improve their practice and learned to do research. We investigate: *How does conducting action research inform the teachers' development of knowledge, skills, and attitudes on the practice of teaching, teamwork with their peers, and the domain of engineering?*

3.4 Action Research for Teacher Development

Many approaches to teacher professional development have emerged. Those currently being adopted range from short, less than one-day training sessions to longitudinal growth via teacher inquiry (Loucks-Horsley, 1996). Action research has longstanding roots in the field of teacher development. Teacher action research systematizes the process of development through habits of reflection about one's teaching and a sense of heightened awareness of their practices and of what was happening in their classrooms (Zeichner & Noffke, 2001). Smith and Fernie (2010) argued that all teachers could use the action research method to improve the effectiveness of their teaching continually. Preisman (2007), a teacher educator, wrote about her experience seeing that action research is significant in teachers' lives, describing action research as meaningful, friendly, and possible.

Virkki-Hatakka, et al. (2013) concluded from their study on developing chemical engineering course methods that action research-based improvement process contributed useful courses, successful learning, and professional skills of the teacher. Capobianco and Ní Ríordáin (2015), working with preservice science and mathematics teachers, suggested that the action research approach taken by the teachers provided valuable opportunities to improve their practice, their understanding of their practice, and the situation in which their practice takes place. All three components of development are necessary for our context as the teachers develop a new field of

knowledge and practice outside their area of expertise. We studied uncertainties faced by teachers during their learning and saw that not only did the teachers face challenges in learning to teach science and mathematics, but also in conducting action research. However, with time, action research assisted in recognizing, accepting, and addressing the uncertainties positively and productively.

Action research, whereby teachers isolate a problem and undertake a reflective cyclical process of finding solutions to it (Carr & Kemmis, 2003), was an appropriate intervention for several reasons. First, the very nature of action research as a tool to prompt reflection allows for questions of challenges in understanding and delivering complex technical content. Second, as a data-collection method, the journal-keeping aspect provides a useful way to understand teachers' reflective processes. Third, the approach provides a fulfilling combination of being able to research while hopefully providing an opportunity for teachers to improve their practice. I summarize the characteristics of action research that presents the reasons for its choice as follows (see Table 6):

Table 6. Characteristics of Action Research

Characteristics of action research	**Citation**
A process whereby problems are studied scientifically to evaluate, improve and better direct decision-making and practice	(Corey, 1953)
Bridges the gap between research and practice	(Somekh, 1995)
A more systematic, careful and disciplined way to observe and enquire with the aim to improve practice	(Kemmis, McTaggart, & Nixon, 2013)
A self-reflective inquiry whose end is greater social justice through the improved understanding of practice	(Carr & Kemmis, 2003)
Should also contribute to a theory of education that is more reflective	(Stenhouse, 1980)
Differs from many other types of research in that the focus is on the doing *by* people not *on* people	(McNiff & Whitehead, 2011)

There is a variety of beliefs as to the aims of action research, ranging from simple problem-solving to improved self-reflection with a higher aim of achieving social justice. Whitehead (1985) and Stenhouse (1975) both argue the value of action research to the individual teacher (in Cohen,

Manion, & Morrison, 2002) is encouraging him or her to observe, reflect on and solve individual problems in the classroom. Therefore, the teachers who participated in this study used the strategies disseminated to them from reflective practice meso-cycle and initiated a research inquiry to understand the area of concern as a first order action research cycle to plan, act, observe, and reflect (Elliot, 1991; Stenhouse, 1975).

3.5 The Community of Practice

The initial professional development using reflective practice (Schön, 1987) evolved into the formation of a CoP, allowing for the teachers (second, third, and fourth authors) and the researcher (first author) to deepen their knowledge in the area of teaching engineering. In the field of teacher education, CoP's are viewed as promising themes for professional development (Bates, Swennen, & Jones, 2011; Hadar & Brody, 2010). Wenger (1998) indicated that it is by developing the three elements of the domain (group's identity defined by the shared area of interest), community (members pursuing the domain through engagement in purposeful activities and meaningful discussions), and practice (tasks and activities developed over time by the community through active and meaningful negotiation of the meaning) that a CoP can be established. Therefore, for this study, we adopt the CoP as our theoretical framework. The notion of CoP is used as an entry point into a broader theory of learning that has several constituent components (Wenger, 1998). In the more comprehensive social approach of learning, four elements are integrated—meaning (learning as experience), practice (learning as doing), community (learning as belonging), and identity (learning as becoming)—to ''characterize social participation as a process of learning and of knowing'' (p. 5). These four elements provide a guideline in evaluating the learning of teachers through the lens of legitimate peripheral participation, where learning is identified as a contextual social phenomenon, achieved through the participation in a Community of Practice (Floding & Swier, 2012).

The CoP, then, are ''groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis'' (Wenger, McDermott, & Snyder, 2002, p. 4). Many CoPs have existed within the context of education and have adopted action research as a strategy for fostering teacher learning

in many domains, such as subject matter knowledge, knowledge of pedagogy, and knowledge of classroom practice (Briscoe & Wells, 2002; Gayford, 2002; Goodnough, 2001).

3.6 Design: Status of Teacher Action Research Projects

The three teachers completed their first action research cycle and are currently implementing the second cycle. All three of them identified their research areas of interest and framed their research questions around the following areas, respectively: collaborative learning, active learning, and community engagement.

3.6.1 Sandra

Sandra's initial starting point entailed research on understanding perceptions of engagement between the local community and the school through the engineering classes, with both the students and community members. She has identified the students' and the community's perception of the center and engineering program and has started to design a supplementary engineering training that integrates the center with the community.

3.6.2 Ellie

Ellie's starting point entailed an inquiry into improving participation of all student team members in engineering classes. She has completed the first cycle and identified preferred ways of engagement for students in teams and is now implementing them in her classroom in the second cycle.

3.6.3 William

William wanted to examine the effectiveness of different active learning techniques for teaching science content in engineering classes. He has completed the first cycle and identified active learning strategies preferred by the students to address their needs and is testing them in his classes.

3.7 Status of LED program during meso-cycle 2

The teachers and I started the discussions on Action Research during the fall of 2018, while the second version of the LED program was just beginning. By the end of fall 2018, Tumaini changed with the start of vocational classes and increased the total number of students from January 2019. Therefore, the program was re-started to include the new students, and a total of five classes were designed. The teachers and I collaborated with the director of Tumaini and the new vocational teachers to design these five classes. The five classes included: (i) primary school section – 14 students; (ii) motor vehicle mechanics section – 6 students; (iii) welding – 2 students; (iv) Electrical wiring – 4 students; and (v) Hairdressing – 4 students. Each section had its own problem scope areas. However, the content from the LED program on the engineering design process and professional competencies remained the same for all sections. The technical content changed based on the problem area identified by the students in each section. Amongst the five sections, two of them received problem statements from external users/clients. They requested Tumaini to help in addressing their problem (a portable energy efficient device to store fish for fishers in the lake region, and a machine to produce charcoal briquettes from pyrolyzed paper for cooking). These two projects were allotted to the primary school section (fish storage) and welding section (briquetting) based on their interests and backgrounds. The remaining three sections identified problem areas within Tumaini.

During the meso-cycle 2, the three teachers in the study were facilitating the primary section as co-teachers, and the three of them split classes every week. Three classes were scheduled for three days during the week, with one teacher handling every day. This decision was made by the teachers themselves to plan and run the classes based on their schedule. By the end of December 2019, the students made prototypes for each problem area, and in the primary section, the students designed a portable solar refrigerator using the Peltier device.

3.8 Intervention and Research Method

The study began with a two-day follow-up workshop to the previous research on reflective practice. During this workshop we revisited the expectation, guidelines, and the central theme for this collaborative group. The first author introduced the teachers to the model of the action research

cycle (Carr & Kemmis, 2003) and discussed potential strategies that are relevant to the context and the CoP.

3.8.1 Data Collection

Journals

Notebooks were intended to provoke reflection on the teachers' experiences before, during, and after class sessions. The teachers used the double-entry (Feldman et al., 2013, pp. 24) format of reflection for their pre- and post-class reflections. A total of 4 journal entries were completed by each teacher for a total of 12 journal entries (sample in Appendix. E).

Interviews

Individual semi-structured interviews (approx. 30 min; protocol in Appendix. G) were conducted with two teachers (Sandra and Ellie) mid-cycle, i.e., halfway through the action research professional development. William's mid-cycle interview was not conducted due to his absence at the center, as he was engaged with his primary role as a social worker in the field for a significant period of time. Final interviews were conducted with all three teachers at the end of the cycle. The interviews gathered more information about the teachers' experiences with teaching engineering, their experiences building a CoP, and their experience with research.

Critical Friends Meeting

Critical friends' meetings included the meeting of the three teachers and me. We participated in a total of 14 weekly meetings where we debriefed about the teachers' weekly journal responses, engaged in detailed conversations about individual teacher experiences in the class, and planned for subsequent weeks. This allowed the chance to explore further and understand each teacher's decision-making and associated classroom challenges. From the meetings, I prepared notes and also the teachers prepared notes and reported them as minutes of meeting to the entire group.

WhatsApp Conversations

WhatsApp, a texting app, was used to serve as a flexible, real-time platform for continuous engagement and virtual collaboration. A group was formed in the app to allow the teachers and researcher to communicate virtually throughout the study.

Member Checking

Upon completion of the first round of analysis, emerging findings were shared with teachers for member checking. An online group call was organized to discuss the teachers' perception and interpretation of the results. The notes from the call was used as a data source in the final round of analysis.

3.8.2 Data Analysis

Data were analyzed using thematic analysis. Braun and Clarke (2006) define thematic analysis as "a method for identifying, analyzing, and reporting patterns (themes) within data" (p.79). At each stage of the study, the data were coded using the following process. First, the data were coded based on the three components of the CoP theory (Domain, Practice, Community), which also is part of the research question (Domain/Engineering teaching, Practice/Teaching, Community/Peers). Second, within the three categories, the data were coded using the four aspects of "meaning," "practice," "community," and "identity," as discussed in the CoP. Third, within these aspects, open coding was performed where a code was assigned to a unit of analysis, which in this study is the sentence (Saldaña, 2015). For example, when teachers discussed the aspects of vulnerability within the CoP, these statements were coded as "teacher vulnerability." Another example was when the teachers described events when learning about research that was challenging. These events were coded as "Challenge Learning research."

These codes were then read, re-read, and synthesized into common categories within the three categories of domain, community, and practice. We later merged these categories to form patterns or trends in the data. These trends were confirmed across multiple data sources. The first author conducted the analysis and discussed the results at various stages with the last author for reliability. To enhance the generalizability of these findings (Huberman & Miles, 2002; Yvonna S

Lincoln & Guba, 1985), we conducted member checks of vignettes of the teachers' responses and later refined these interpretations based on the teachers' (second, third, and fourth author) feedback.

3.9 Findings

In this section of the paper, we discuss the results of the analysis as four significant themes using the structural framework provided by CoP. We use the three components of the CoP (Domain, Community, and Practice) to situate the themes under the specific elements to answer the ways teachers have developed knowledge, skills, and attitudes about their teaching, their peers, and engineering. We briefly highlight the findings from the first cycle of our DBR, where teachers adopted reflective practice strategies in teaching engineering, as they help better situate the results of this research. Reflective practice enabled the teachers to recognize their competencies and acknowledge those of their peers thoughtfully. The sheer act of identifying the competencies led to the mutual engagement, whereby teachers established an active platform to share and learn from each other (Author, forthcoming). Reflective practice also resulted in three forms of identities that evolved at various stages of development. The three identities were: (i) fully formed members of the CoP, (ii) an engineering teacher continuing to learn the practice and in the trajectory of becoming one, and (iii) an engineer, who applies the knowledge and skills of the field to their practices.

3.9.1 Theme 1: Engaged Diversity, Shared Learning, Sense of Vulnerability Contributes to Joint Enterprise

Diversity is what makes a community of practice a community where participation in the practice is possible and productive (Wenger, 1998). The untrained teachers in particular bring a multitude of diverse aspects to the community of practice, since their initial training, background, and professional roles are different. Wenger (1998) discussed that the diversity of the members in CoP directly influences each other's understanding of the practice and further contributes to the wholesome development of the enterprise. A joint enterprise is the result of a collective process of negotiation that leads to the pursuit of the domain (Wenger, 1998). In the engineering teachers' community of practice, the negotiated collective goal was to improve the practice of engineering teaching. As the teachers began to reflect and mutually engage in the second cycle, recognizing

the diversity was an added strength in tackling the common goal. According to Sandra, the diverse perspectives brought by the team pushed her to learn and contribute better to the collective goals.

> Initially I felt like we all have our own ideas or ways of how to do this, and I just want to do it my own way, because with that, I know the outcome. You know, but now, you're asking me to work with people, with so many uncertainties, with so many ideas, with so many different personalities, but right now, that's the beauty of it. I look forward to hearing what people have to say about something. I'm eager to know, "What does Ellie think?" or "How does William do business?"……. It's really fun. Helps me understand how we can tackle this. It has its own frustrations, but that's the beauty of learning it. You learn that people have different personalities, different temperaments, different ways of thinking, it's really helpful for the group because at the end we all want to become good engineering teachers for our students. (Sandra, Final Interview)

Appreciating the diversity was reflected in Ellie's journal during the middle of meso-cycle 2. When prompted about her learning in CoP, Ellie noted that:

> Our community has doubled up since the beginning and has given the community the privilege of diversity and it has been refreshing. I have not only learned how to listen to others but also how important it is to empower and strengthen one another as we grow. Listening to each one of my teammates teach us something distinctively different but very crucial to not only the CoP but also to our organization has been enlightening. Key lesson learned: Together everyone achieves more! (Ellie, Journal, March 4, 2019)

Recognizing the diversity of her team also enabled Sandra to enhance her engagement by continuing to learn from others and sharing her knowledge with others. She noticed, as a result of shared learning, it was not only the growth of an individual but also the collective growth of the team. During the final interview, Sandra said:

> And allowing other people to teach me and also allowing other people to learn from me, that has been a humbling experience, and especially in a field that none of us has ever been into, even I think for engineering students maybe in Moi University, they don't get to do what we do. Here we're all learning, to give our best, so it's not just one person excelling, but it's CoP excelling, that has been a very a humbling experience and fun. (Sandra, Final Interview)

Though engaged diversity and shared learning opened the doors for the teachers to participate and work towards the common goal, it was not until the teachers accepted to be vulnerable within the CoP that full participation happened. All the teachers shared this particular notion at the beginning that they were reserved and did not want to appear weak in front of the others. For example, Ellie shared her journals privately with the researcher instead of the common group when she reflected on challenges she faced in her class. One of her journals read:

> "I was wrong in class. We solved the problems given to us on the series and parallel circuit and I realized after we did, I taught them the opposite. I feel embarrassed. I didn't see the video that Dhinesh shared properly and now I see where my mistake was. I need to go back and change it in the next class." (Ellie, Journal, February 19, 2018)

After sharing the journal, the researcher and Ellie had further conversation on the reason for not sharing it in the group. Here we provide an excerpt from the conversation in WhatsApp.

> *Ellie:* Here is my previous class journal. (Attached image)
>
> *Dhinesh:* Thank you, Ellie. Good job finishing it and sharing it with me. But, could you share it in the group with the rest of the team, so they also know about your classes and be reminded about their journals.
>
> *Ellie:* Hmmmmm hmmmmm. Dhinesh I don't want to. This week was not good to me. I will share the next one in the group.

However, as the teacher collaborated further and began to demonstrate vulnerability, they learned that it led to range of possibilities to improve each other's teaching. For example, Ellie discussed in detail one of her reflective moments during the second cycle. She shared:

> Let me say first, even if I haven't shared it with anyone, I'll tell you now, CoP has made me like mentally changed on my teaching and how I interact with people. Because when you went to college and trained as a teacher, you will feel like you know things. I teach you people who are not trained teachers. Working with Sandra and William, I would say, "I think I know much better than them," that's human. But I saw William one day was teaching the class so smoothly. And I remember there was a class with math in it that I was supposed to teach, and it was so complex to me. I went and told Sandra, "I'm having a very bad stomach, can you please help me teach my class, I just need to sleep." And she offered me to sleep at the dorm, but I was like, "No. I want to sleep on my desk." Because then I would be able to hear what she's teaching. And I came here, I closed that door, and then I moved my seat to the door. And Sandra was teaching so smoothly. She didn't even have struggle of teaching. And that challenged me. There was something I was trying to escape from but someone else is teaching it so perfectly. Then I noticed, I need to consult. If I bring Sandra close, I will know the secret of teaching this. I will understand better about this. CoP made me realize that I cannot do this alone. I will say ego sometimes makes you think you know I did not, but now I know. Yeah, I cannot do it alone. (Ellie, Final Interview)

Ellie demonstrated vulnerability via a fluidic state of being that is influenced by the way she perceived her situation as an engineering teacher and a trained childhood development teacher. Her identity as a professional teacher gave her a sense of confidence in teaching; however, as the subject matter was not familiar to her, she faced issues in facilitating them. Observing William's class acted as a trigger and changed her state of vulnerability. Sandra and William too resonated with experiences of vulnerability in the CoP and presented that conveying "…I don't know; I want to learn. Can you tell me?" (Sandra, Mid Interview) developed the openness and trust amongst each other to jointly progress towards the goals. From a cultural perspective, the teachers' discussed (anecdotally) at various instances during their engagement in the CoP, that it was not appropriate for them to be discussing about feelings or their weaknesses. Therefore, demonstrating vulnerability and seeing it as a driver for growth was an incredible growth for the teachers.

Diversity and shared learning contribute to the sustainability of the community, while in parallel negotiating the enterprise to develop practice. However, vulnerability or openness is not explicitly discussed by Wenger (1998) as a critical factor of community formation or operation. Critics of the CoP have also highlighted the missing element of trust in the theory (Roberts, 2006). Our results show that the sense of vulnerability within the engineering teachers' CoP was a crucial factor in allowing for mutual engagement and further the negotiation of the enterprise.

3.9.2 Theme 2: Meaningful Learning Experience of Students – Key Factors for Pedagogical Content Knowledge Development and Attitude Changes

Shulman (1986) defined Pedagogical Content Knowledge (PCK) as the most useful way to represent and formulate the content, which will make it comprehensible for the learners. With PCK, instructors understand what makes the learning of specific concepts easy or difficult and the preconceptions that diverse students bring with them to the classroom. A study of secondary science teachers suggested that the definition of PCK is much broader than merely possessing the knowledge to teach a specific subject (Lee, 2005). According to the study, PCK includes the application of the knowledge to make pedagogical decisions that will improve students' understanding of a subject.

The teachers in the study demonstrated at various instances through the second cycle that they were motivated by seeing the student's interests and needs in learning engineering and the relevance of the program for their students—this motivation directly affected the development of PCK. For Sandra, seeing the interest of her students learning engineering helped her to learn to teach the class. She developed skills to facilitate the course better to engage the students meaningfully. During the mid-cycle interview, Sandra said:

> I think one thing that has really helped me is the interest of the students. Seeing students learn something that they were not familiar with, and their interest and then wanting to know more, it pushed me also to want to know more so that I'm always prepared to deliver in class, and also to assist where I can to help students learn. (Sandra, Mid Interview)

However, for Ellie, the scenario was different. As a trained teacher, she brought into her classroom pedagogical knowledge, but the content was new to her. Shulman discussed PCK via six different elements. Among them, the curriculum knowledge, knowledge of representation of the subject matter, and the general pedagogical knowledge contributes to the teachers' confidence

in the content being taught and assist with preparation. Ellie was confronted in real-time with the challenges of lacking content knowledge.

> Prototyping was my topic. I taught prototype, but the content was supposed to be taught in two class of each two hours. It could have end in the next class, maybe the first hour. But I taught prototyping for five class sessions over three weeks. Because I took it like a very simple topic, and, that's where my problem was. I understood one part of the topic. I did visual prototyping and I did not go deeper on 3D. So when I was doing the visual, I was doing it perfectly. But when it reached to the 3D, it was very difficult to a point when I'm halfway or 30 minutes from teaching, I have taught for 30 minutes I would realize, "Oh my God, I did not understand this content." (Ellie, Final Interview)

At this challenging moment in her practice, it was the needs of the students and their participation in the class that motivated Ellie to overcome the challenge by spending more time in preparing for the lessons and engaging with her team in the CoP.

> The boys are already doing the practicals. I'm like, "I need to tell them what, this is happening." And it was hard for me. So, it took me so much time and it made me feel so bad that it was not like that on my plan. Seeing students confused and ask many questions made me realize I need to do more. So, it helped me know how to prepare for my class and to go to class when I'm fully prepared to answer any question, to do any activity, and to plan it, to make it in order and to keep time on it. I found help. I asked you (first author) many questions on how to teach 3D, then I asked my team for tips. So, it was good then. (Ellie, Final Interview)

Motivated by the need for meaningful learning of the students, Sandra identified gaps in her teaching and made changes. One such change that Sandra brought was to include a five-minute discussion break after teaching every topic. She realized the students had a hard time understanding the complex and abstract contents in engineering, like the design process. Therefore, to ensure learning, she allowed students during this discussion break to summarize and teach each other.

> It was, I think last year, yes, when I decided to try out the five-minute break, dividing the students into different groups and for example after every sub-topic, you allow the students to have like five minutes of discussion, to just discuss what they have understood, explain to one another, and then ask questions. Because the content was different. It's not straightforward. Like EDP. And I saw that working, something I had not seen in the other classes I had attended on how I had seen other teachers teach. And I was able to cover the content and not just covering the content, but the students were able to understand, which was key for me because I don't want just to go to class and just finish up the 40 minutes or the one hour, everything that was supposed to be finished, but it's more of, "Are the students understanding what the content is all about?" (Sandra, Final Interview)

The changes Sandra brought in her teaching and discussed it in the final interview was also reflected in her journal entries. Her journal entries showed that she began enjoy and be more

confident about the classes as she began to make informed changes and improve her teaching. One of her journal entries stated:

> The class went very well today better than I expected. During the first few minutes as we were doing the recap the boys were very active and they could recall what they learnt last term on the topic. I had planned to spend the first class on doing the recap and covering both the advantages and disadvantages of the thermoelectric refrigerator, but we spent quite some time on the recap and had to cover the remaining part from 2 pm. We did the five-minute recap as I have did before after every topic and so we took more time. But I saw the students understood the topic. We managed to watch two youtube videos to emphasize more on what we had learnt before. I feel that the class was successful today because we covered what we had planned for and the students have a better understanding of the topic. The only challenge I had was the activity that we were to do but couldn't because of time as well as lack of thermal paste or rather I couldn't find it for use. I really enjoyed today's class and I felt more confident about teaching. (Sandra, Journal, September 12, 2019).

During the first cycle of the DBR, the teachers discussed the complexity and challenges with the curriculum given their unfamiliarity with the subject matter. For Ellie, as discussed in theme 1, she was challenged with mathematical content in the course. In addition to engaging in the community, the benefit of the curriculum for the students was a key factor in changing the attitude of Ellie. She began to participate in practice with a positive mindset.

> Some of the factors that made me improve in teaching. I think accepting and having a positive mind that I can teach. It used to be a little bit difficult for me to do it because I was not so sure if I want to do it and again I wasn't so sure if I'm doing the right thing. But since I get to know what I'm doing is right and benefiting students and other people are learning from me and I have students who are depending on me to teach them that, I developed an extra ordinary interest. It made me love what I do. (Ellie, Mid Interview)

For both Sandra and William, research was not a new topic. They discussed on several occasions during the second cycle that the experience with this research was nothing like their previous experiences during their bachelor's program where they had to perform a research project. They noted their past experiences were not meaningful or relevant but were presented only to meet the degree requirements. However, in professional development, they were able to connect better and see its relevance given the better learning experience it created to the students.

> So, the traditional way of teaching was, go to class, deliver content, students pass exams, or they don't, but you're done with the syllabus or whatever you're supposed to cover, but I think with something like, the research, it's been more intentional, deliberate and really, really active in class. Now research is actually improving learning for the students and also the teaching methods of the teacher, because you're observing, you are collecting the data, like all these things now have become very .... Like, "I tried this in class, it didn't work." or "I tried this is in class, it worked. Why did it work? Is this something that we continue?

> Yes." So, being a very intentional and deliberate teacher in class, not just for the content, but the well-being of the students becomes now your priority, in a learning space. (Sandra, Final Interview)

Our analysis of the teachers' narratives revealed that placing students at the center of their practice mediated the development of their pedagogical content knowledge and attitudinal changes to their practice. For these teachers, holding students' needs and students' interests as a priority aligns the commitment and purpose they have with their roles as engineering teachers.

3.9.3 Theme 3: Critical Friends Meeting and Reflective Journal – Key Shared Repertoire in the CoP

Teacher action research typically involves small-scale inquiry undertaken by individual teachers addressing a problem of significance in their practice through a self-reflective cyclical process of plan, act, observe, and reflect (Liston & Zeichner, 1990). Teacher action research, though a self-inquiry, allows for various forms of collaborations with fellow teachers and teacher-researchers (Feldman et al., 2018). One such type of collaboration is referred to as a "critical friend partnership," (Ponte, 2002) where the fellow teachers who are willing to support each other's inquiries engage in "examination, critique, and dialogue" (Blake & Gibson, 2020, p. 4). In our study, during the beginning of this teacher professional development, the teachers established ground rules for this collaboration. One of the rules was to engage in the group to support each other without making any judgments. In other words, be "critical friends" for each other. Though established as a rule, the process of forming effective critical friends' relationships is complex (Wennergren, 2016). During the mid-cycle interview, Ellie discussed her challenges to collaborate with the other teachers given the different schedules and nature of professional work held by each of them.

> I'm working with people from different departments and they have different class, different schedule. So, most of the time, I sometimes I feel like I need to do this as a team with them but they're not available, I end up doing the class alone. If we can do it as a team sometimes it makes me feel better because I know other people are benefiting from me and I'm also benefiting from them in one way or another. (Ellie, Mid Interview)

The challenge of meeting other teachers to collaborate further distanced Ellie, as she was in a dilemma about the number of times she could consult her critical friends. Though her feeling

to ask frequently is understandable given the new subject matter and complex contents, she could not do it, and this further led her to question her own efficacy as a teacher. She shared:

> People are different. To me it made me feel like, "Do I need to ask like every specific class? Do I need to go and maybe ask about classes every day before I teach? That means I don't understand. I need to get clarification from someone else for me to be able to teach. And if that so, then I'm not doing the right thing. As a teacher I should understand what I'm going to teach." So, for me, to some point, it made me feel bad that I have to consult so much because I wanted to do it daily. (Ellie, Mid Interview)

Halfway through the professional development, the teachers created a schedule to hold the Critical Friends Meeting (CFM) on Wednesdays every week. This new schedule provided the platform for further meaningful and consistent collaboration. During the final interview, Ellie said:

> But the positive side of it now is that, at the end of ... Maybe after CFM meetings on Wednesday that were very useful and very effective to me, after all those meetings, I would take that opportunity and ask from colleagues, "How did you find the class? How did it go?" And without even telling them that I'm having a problem in my class, I managed to get a feedback or to get a reflection of what I should do and what I needed to do and by taking their journal and doing that. (Ellie, Final Interview)

Therefore, CFM became a platform and resource for collaboration and engagement: in other words, according to Wenger (1998), a shared repertoire. A shared repertoire is the third characteristic of a community in addition to mutual engagement and joint enterprise. Shared repertoire comprises the resources created for the negotiation of meaning as a result of jointly pursuing an enterprise (Wenger, 1998). Similar to CFM, the role of reflective journals strengthened and became a common artifact using which meanings were negotiated. Like Ellie, William found the CFM to help him make meaning of the engineering curriculum and the teaching endeavor. During his final interview, he shared:

> Okay. Through our CoP meetings every Wednesday evening, it has been very helpful for me, because I get to understand what we are going to teach in class. So, through those CoP meetings and sharing ideas among ourselves and telling each other, it's become more helpful for me because I understand what we're up to after all. So, it has been helpful for me, especially those meetings. (William, Final Interview)

Kember et al. (1997) from their study concluded that critical friendships had been found to have varied roles. The friendships are often constrained by hesitancy, initial shyness, trust, power struggles, and resistance to learning (Blake & Gibson, 2020, retrieved from Golby & Appleby, 1995). In our study, we see that once such constraints are addressed, critical friendships have the capacity to break power barriers and serve as a safe and equitable environment. Ellie discussed

how she was able to see the CFM as an equal space where she was able to engage critically even with her boss, the director of the school.

> But through COP I am able to talk to anyone depending on the levels and standard. That group is perfect because it breaks standards. So, when we go to that group, we become equal. It doesn't matter the age, the level of education, which department you're doing, either you are employed or you're volunteering, even like gender, man and ladies, no, it doesn't have that. So when you're in COP, you would give opinions. People would take your opinion very seriously. People would listen to you.
>
> I remember there was a day I felt so good when we were at COP and the director said, "Ellie, may I borrow your journal?" I was like, "Oh yeah, you can take it." And he took it, he went, and he did not understand it. He called me, "Can you explain these? Why are you doing it this way? Why are you sticking these papers on this? Why do you need to write this on this?" And I know it was a lot of work to explain to him and to make him write that, but for me it made me feel so satisfied that irrespective of him being a director, he needs something from me. (Ellie, Final Interview)

Though the CFM evolved to become a beneficial activity at then end, at the beginning the teachers were limited by their cultural norms to be critical to each other. It was not that they cannot be critical to each other but culturally the practice of becoming critical was understood to take a long-time including that of developing strong relationships. The teachers also held an impression that only the superiors by profession in their organization can be critical and cannot be friends. For example, during a conversation on WhatsApp at the time of meso-cycle 1, Sandra informed Dhinesh about the reservations the teachers may have for critical feedback. Dhinesh presented his critical feedback to the teachers during a virtual meeting prompting them to be more thoughtful in preparing for their classes early. The WhatsApp conversation between Sandra and Dhinesh stated:

> Sandra: Wow! That was something.
> Dhinesh: Did something happen wrong? At the end, I could feel the tension amongst everyone.
> Sandra: Haha. Yeah. You were brave to Kenyans. Lol. It is not the usual. We don't just say like "you have made a mistake." I know it is weird. I too find it difficult as HR I have trouble telling people when they are not doing it right. I am not like the Kenyan they stereotype too.
> Dhinesh: Oh wow! Thank you for telling me that. I did not realize. That totally makes sense. What is a better way then? How do Kenyans be critical?
> Sandra: Haha, I doubt we are ever like that. But what we can do is be clear. Tell that it is important for us to be honest and clear just like how the students are. If we keep being like that it will become normal.

Sandra's critical thinking from observing the situation during the meeting helped us in ensuring a culturally appropriate way of engaging the teachers to become critical friends. Therefore, from the situation of being aversive to direct feedback at the beginning towards

becoming critical friends and seeing the CFM as an equal space as explained by Ellie is a significant transformation.

Both CFM and reflective journals were a new activity and tool respectively to the teachers and to the alternative school, which has now become the repertoire of the engineering teachers' community of practice. According to Wenger (1998), the repertoire "includes the discourse by which members create meaningful statements about the world, as well as the styles by which they express their forms of membership and their identities as members" (p.83). In our teacher professional development study, the critical friends meeting has become a safe and equitable space where teachers engaged in deep conversations on their practice as professional friends (Blake & Gibson, 2020). The journals have become documents of shared histories of the practice that can be used within CoP for mutual learning.

3.9.4 Theme 4: Engineering Design Process and Action Research – Interconnects with Other Practices

Wenger (1998) theorized that a CoP does not exist in isolation, as their members link themselves with other practices. The social nature of the CoP allows for connections across boundaries to other practices and, in turn, makes the existence and continuity of the CoP a meaningful one in the nexus of many practices. Our LED curriculum is designed with the Engineering Design Process (EDP), a systematic problem-solving approach, as the main thread. As the teachers delivered the curriculum and absorbed the EDP, they found it relevant and applicable to their practices. Sandra, during the mid-cycle interview, shared her understanding of the EDP was what she has been waiting for to solve problems in her other practice. She shared:

> I look at the community, not just the outside community, but Tumaini, and I see the gaps that are there. In my role as a program coordinator, I want to build relations and networks for the center with the external community. But not just that. I can see what we can do, but now between what is there and what should be there, that design process was the one that was the missing link. For now, I know how to address that. Before, I was like, this needs to be done but I don't know how to do it. And when you ask around, everyone is like, "We also know there's this gap, but you just figure out how you're going to sort it." But now I know that there's this problem, this is what we need to do, this is what we should start to get to this point. I have already started using it in my other areas of work. I am planning a program for the community using that. (Sandra, Mid Interview)

Both Ellie and William, too, resonated with the applicability of EDP in their other practices, both personal and professional, to solve problems. Similar to EDP, Action Research played a similar role for the teachers where they identified relevance to use the knowledge and skills from research in their other practices. For William, research became a tool to use in his role as a social worker to understand his students better and support the gaps in their mental well-being as a mentor.

> Action Research is playing a big role because I can know, for example, the students who are coming here through my own I can create an avenue that I can understand those students who are coming here. To know them as their mentor, how they are better. So, after doing research I can know more about the student's mental challenges, who will be coming here I can know them much better. Their psychological effects or how are they affected especially on missing their drugs. So, I can do my own research to know more of them. So, I can transfer that knowledge to knowing my students who are coming in. (William, Final Interview)

According to Wenger (1998), these tools, concepts, terms, artifacts that are a result of participation and reification in the CoP can serve as interconnections with other practices of the members and can even invite external practices to be linked. He called these objects of interconnections "boundary objects". Our analysis shows that both EDP and Action Research have rightfully become boundary objects that the teachers use to interconnect with their other practices. The interconnection enables the teachers to view the participation in the engineering CoP as relevant and meaningful.

3.10 Discussion

. In this study, we have identified the teachers' developing relationships across four components: their teaching practice, their community of peers, the discipline of engineering, and the task of research. All four themes contribute to each of the three elements in specific ways (represented in Figure 14). However, they should not be considered as mutually exclusive and particular to the component most directly expressed. As explained by Wenger (1998), the elements of the CoP and various factors influencing the development of them co-exist based on the participation of its members. The following conclusions can be drawn from our investigation on the ways action research informs untrained teachers' knowledge, skills, and attitudes development on their (i) practice of teaching, (ii) community of peers, (iii) discipline of engineering teaching, and (iv) domain of research.

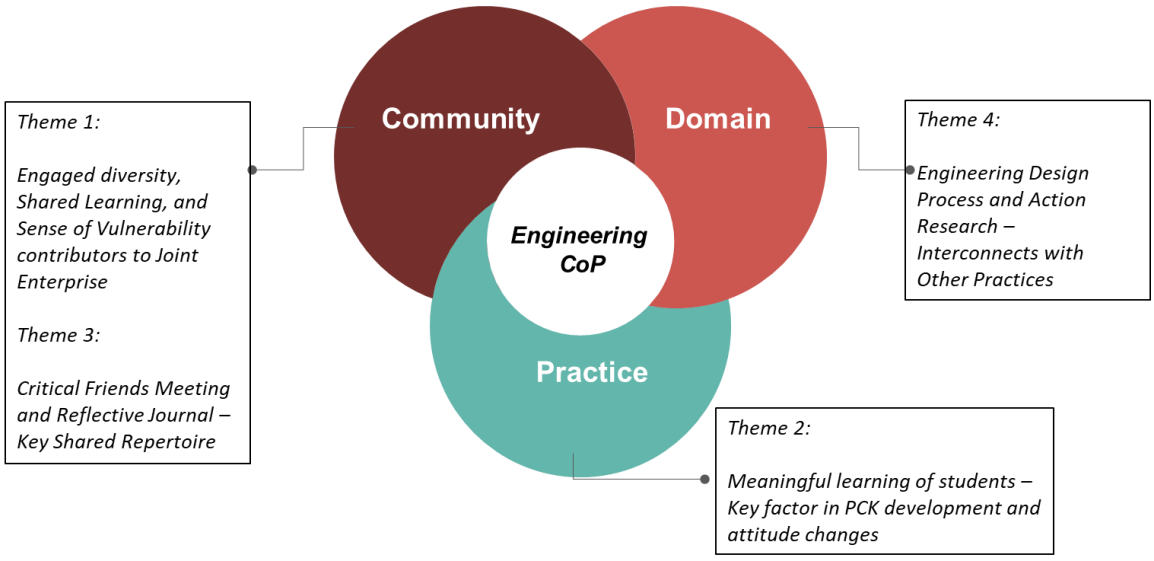

Figure 14. Results from meso-cycle 2 contributing to the CoP elements

3.10.1 Community

Wenger (1998) defined the three dimensions that form and sustain a community as mutual engagement, joint enterprise, and shared repertoire. As discussed above, cycle 1 of our DBR analysis revealed that reflective practice strategies enabled the teachers to engage and establish a foundation for the CoP mutually. In this study, it is evident that action research has actively contributed to the other two dimensions of the community. Joint enterprise implies that the community possesses common interests and collective goals (Wenger, 1998). Membership involves a commitment to an endeavor that is considered relevant to all members of the community and can be mutually accountable. As a sense of community was built, diverse perspectives of the members, and sharing similar experiences and learning through the interaction with the others resulted in professional growth in the enterprise. These findings are in line with that of Patton and Parker's (2017) study of a CoP for physical education teacher educators.

The stages of evolution of the community are also similar to the three-layered model proposed by Hadar & Brody (2010) regarding the effectiveness of CoP in teacher education, where each layer is a prerequisite to the following. The initial layer represents the breaking of isolation. At this stage, there is space for safe discussion, social and professional interaction, and cross-area discourse resulting in the development of a group that could make professional connections. This communication around the standard relationships then leads to the second layer of improved

teaching and/or research. Professional learning regarding research and teaching and a resultant increase in self-efficacy and competence provide the third layer of the model.

Additionally, our study sheds light on a critical factor that enables the creation of safe space, advanced levels of participation, and a sense of vulnerability. The willingness of the teachers to overcome cultural beliefs such as showing emotions as weakness, and blur the boundaries between the personal and professional relationships of their peers (Lasky, 2005) opened the doors for development as engineering teachers. Further, the nature of action research enables critical collaboration placing the participants on a meaningful growth trajectory via critical friends conversations (Feldman, 1999) and reflective journals (Corbin Frazier & Eick, 2015; Ruiz-López et al., 2015).

3.10.2 Practice

Practice, according to Wenger (2010), is "something that is produced over time by those who engage in it through active and dynamic negotiation" (p. 180). Our analysis shows that the teachers negotiated the development of pedagogical content knowledge of engineering teaching and experienced attitude shifts to create meaningful learning experiences for their students. Action research has enabled teachers to develop unique teaching knowledge and make informed choices in applying it by changing their practice to meet students' needs. Chai et al. (2011) have argued that teachers with such an inter-related set of knowledge areas have a sense of themselves as highly adaptive and will be better prepared for the dynamic evolvement of the teaching practice. Gourneau (2005) discovered five teaching attitudes of effective teachers, and our teachers demonstrate strongly the fourth attitude of fostering individualized attention to provide meaningful learning opportunities for all students. The teachers have, on various occasions, expressed the other teaching attitudes listed by Gourneau (2005); however, we are not discussing it here in detail as that is not the focus of our study.

3.10.3 Domain

The teachers transferred knowledge from engineering teaching and research to other practices and demonstrated that they care about the domain being pursued (Wenger, 2010). They have developed expertise that is transferrable and has become part of themselves both

professionally and personally. The Engineering Design Process as a problem-solving methodology spans boundary from engineering to other fields. The teachers in this context view the school community as filled with opportunities to solve various problems and, in the process, engage the students in learning. Action research, however, is a complex and demanding process (Avgitidou, 2020). Therefore, it must be an endeavor that helps teachers grow professionally, personally, and politically (Noffke, 1997) to fully participate in the practice. The teachers view research as contributing to the joint enterprise of engineering teaching, while also supporting the goals of the institution at large and their career goals.

3.10.4 Conclusion

In conclusion, the untrained teachers adopting action research as an advanced professional development after embodying reflective practice demonstrated growth across the three elements of the CoP. The results of this study must be understood, considering its limitations. The results are limited to generalize based on the context of untrained teachers. The teachers in the study did not receive any form of monetary benefits, and when they began the professional development were solely motivated to pursue the benefit of the institution. However, as the design-based research developed, they are currently able to receive certification and transfer continuing education credits from the first and last author's institution. The first author provided the ongoing support during the development to the teachers' and mid-way in the program he moved full-time to the location of the school in Kenya, which might not be feasible in all situations. Therefore, the teachers were able to get better support and individualized attention to their action research projects.

3.10.5 Implications

Implications from the study suggest that action research built on the base of reflective practice is a powerful mechanism that empowers teachers to actualize their teaching and learning of content, pedagogy, and students. Action and reflection are intertwined and thus foster the development of teaching by integrating the perspectives of both research and practical action in class (Carr & Kemmis, 2003; Whitehead, 1985). This second-cycle of DBR has strengthened the foundations of a longer-term collaboration and enabled teachers to improve the practice. Unlike the first cycle that resulted in the construction of identities, the second cycle has shown results in

the development of practice. As the next step in this design-based research, to advance their understanding of their teaching and strengthen their identities as engineering teachers, we are working together within the CoP to establish a mentorship program where the three teachers will mentor four newcomers from the school into the CoP. These efforts will inform a sustainable model for strategic teacher development to enable teachers without engineering content background to become critically reflective and evidence-based engineering instructors.

4. MENTORING NEWCOMERS IN A COMMUNITY OF PRACTICE

Radhakrishnan, D.B., Kimani, S., Wairimu, E., Kimutai, W., Kimani, S. and DeBoer, J. (in preparation). Mentoring newcomers in a Community of Practice: The role of mentorship in sustaining a teacher professional development program.
Targeted Journal: *International Journal for Coaching and Mentoring in Education*

4.1 Abstract

In this study, we discuss mentorship as the third meso-cycle that improves upon the outcomes of reflective practice and action research activities undertaken by the teachers in the previous 2 meso-cycles. Chapters 2 and 3 have shown that upon adopting and using reflective practice and action research, teachers demonstrate improved levels of knowledge and skills in facilitating the engineering program. In the "new image of teacher development," Cochran-Smith and Lytle (2001) emphasize the need for professional development to be continuous and long-term. Therefore, the established CoP must be sustainable and provide the structural framework for continuous development to occur. The sustainability and continuous development of knowledge and practice in a CoP happen through expanding the CoP over periods of time and different phases of the community. Expansion of CoP means welcoming new members in the community who can be guided by mature practitioners through the process of 'legitimate peripheral participation.' In this study, I discuss the role played by the experienced teachers in the engineering community of practice to mentor the incoming teachers and how it strengthened the knowledge, skills, and attitudes of the mature teachers. Results indicate that mentorship enables matured practitioners to induct newcomers and develop a shared understanding of the practice. We also find that mature teachers construct positive identities as an engineering teacher. The study has demonstrated mentorship as part of a robust step towards a long-term, self-sustaining model for untrained teacher professional development in engineering.

Keywords: mentorship, teacher professional development, design-based research, untrained teachers

4.2 Introduction

Motivated by the development of the teachers from the previous cycles (reflective practice and action research) and the expansion undertaken by Tumaini to include more students into their educational program, mentoring became a transformational tool (Feiman-Nemser, 1996) for increasing and enhancing the quality of the teachers at the center. Mentoring as a development tool is a means of rewarding and sustaining skillful teachers while building a renewed, re-energized professional culture with a concentration on improving teaching and learning (Feiman-Nemser, 2001; Huling & Resta, 2001). There is no universal definition of mentoring (Fletcher & Mullen, 2012), and mentoring is a contested practice (Kemmis, Heikkinen, Fransson, Aspfors, & Edwards-Groves, 2014) in which different concepts, such as mentoring, supervision, coaching, etc. are used interchangeably (Sundli, 2007). Mentoring can be performed in many contexts, be based on a variety of purposes and theoretical approaches (Dominguez & Hager, 2013; Hobson, Ashby, Malderez, & Tomlinson, 2009), and be performed under varying levels of duration and intensity (Bullough Jr, 2012; Ingersoll & Strong, 2011; Strong & Baron, 2004).

In this study, we investigate critical aspects of mentoring within a design-based teacher development project, explore the various ways mentor teachers build relationships and develop artifacts, and theorize about significant events, tensions, and dynamics that will lead to knowledge and skill development. This study is guided by the following question

> *How does the act of mentoring newcomers support in the development of mature teachers' knowledge, skills, and attitudes about their practice of teaching, their teamwork with peers, and the discipline of engineering?*

We begin by explaining the micro-cycle of analysis through which mentoring was identified as an activity in the TPD and the literature review discussing mentoring in teacher development and its various benefits. We then outline the situated perspective of mentoring that provides an authentic framework in which to position teacher learning in engineering education. Next, we present the design micro-cycle of the intervention and status of the LED course during the time. Finally, the evaluation micro-cycle explores participants' experiences in this study to better understand the influences of teacher mentoring that contribute to their growth.

4.3 Analysis:

4.3.1 Overview of TPD at Tumaini and the emergence of Mentoring

During a critical friends meeting held in September 2019 amongst the three teachers and the first author, three major concerns were raised by the teachers:

1.) The CoP has grown now due to the start of the vocational school at Tumaini. We have four new members. There are serious concerns in terms of the interest of the vocational teachers and their participation. We believe it may be due to a lack of guidance. How do we become inclusive and open for the new teachers in the CoP?

2.) For the primary school section, we have improved our teaching and learning. However, we still get questioned on our ability to teach engineering by visitors, as well as now by the vocational teachers. The vocational teachers do not know EDP (Engineering Design Process), why we do journaling, why we do research, and so they ask, "are we sure, we are doing the right thing, and we know what it is?" How do we demonstrate our capability?

3.) The professional development program and the practices we have learned have become instrumental for Tumaini and us. These practices can benefit anyone at Tumaini and not only the engineering group. How do we maintain this and make it sustainable for Tumaini?

(*Summarized from Researcher Field Notes, September 6, 2019)*

As described in the previous two chapters, undertaking reflective practice and action research improved the teachers' engineering teaching knowledge, skills, and attitudes; in particular, these activities provided tools and pathways to resolve challenges using the competencies in the community (refer to discussion sections in chapters 2 & 3). However, the primary educational problem to be addressed via the design-based research study is untrained teachers' continuous professional development in fragile contexts. The three concerns raised by the teachers above needed to be addressed to solve the main educational problem. After discussions with the teacher participants, as well as an extensive literature review and theoretical understanding of CoP, we finally identified mentorship as a design solution, which is described further in the sections below.

We regard mentoring as an activity, a process, and a long-term relationship between an experienced teacher (mentor) and a less experienced teacher (novice) that is primarily designed to support the professional development to facilitate newcomers' induction (Hobson et al., 2009) into the culture of engineering teaching. In our study, the experience of the teacher is characterized specifically in regard to teaching the LED course. The professional development of mentors embraces the transition from an experienced teacher to the position of mentor and mentoring practice, along with teaching practices (Orland-Barak, 2001). These transitional processes imply knowledge and skills to master the means of communication and learning and identity formation (Achinstein, 2006). However, Izadinia (2015) argued that little is known about the role of mentoring in the development of teacher identity despite the broad agreement on the importance of mentoring practices in the field of teacher education.

Studies on teacher mentorship have focused mainly on the development of early career teachers who receive mentorship and not on the mentors themselves. So, adding to Izadinia's argument, we find that even little is known about the identity construction and knowledge development of the teachers who are doing the mentoring. One explanation for this could be that mentoring teachers studied in the field of teacher education and professional development are teachers with multiple years of professional experience. Whereas, in informal spaces, particularly fragile settings, teachers with multiple years of experience, and engineering teachers in particular, are difficult to find. Due to the lack of literature on teacher professional development in informal spaces, we draw upon best practices and recommendations for mentoring teachers from the field of formal teacher education and both pre- and in-service teacher professional development. In many ways, the professional growth that is necessary to become a mentor is similar to the developmental stages that new teachers experience in their first years of teaching (Orland-Barak, 2001). Therefore, we contend that teachers who have developed self-awareness of their practice and teaching and learning knowledge and skills qualify as experienced teachers.

Mentors' professional knowledge is highly practice-oriented and emanates to a great extent from mentors' own professional experiences and preferences (Clarke, Killeavy, & Moloney, 2013; Ulvik & Sunde, 2013). Additionally, instructional contexts have been found to have a strong influence on mentors' conceptions and practices of mentoring (J. Wang, 2001). According to Hobson et al. (2009), the largest body of research evidence seems to deal with mentors' critical reflections and mentors' way of acting or understanding their teaching practices (Abell, Dillon,

Hopkins, McInerney, & O'Brien, 1995; Clarke et al., 2013). It is also highlighted that mentors can learn current knowledge or new perspectives from their mentees. For instance, in a Norwegian study of new upper secondary teachers and their mentors, Ulvik & Langørgen (2012) find that mentors learn from mentees about issues such as youth culture and ICT, gain up-to-date-knowledge about curriculum and subject matter, and listen to the alternative perspective of mentees. This finding is most relevant in contexts where the mentors are highly experienced with a substantial number of years into their practice, and the mentees are a novice or are even still student teachers. However, it is relevant for this study to note that there is an exchange of knowledge that occurs during the mentorship process. In the context of Tumaini, knowledge and skills that the three mature engineering practitioners lack on the specific technical domains (welding, motor vehicle mechanics, hairdressing, and electrical wiring) is the expertise of the incoming engineering teachers who are certified technical instructors for the vocational school. This allows for the possibility of an exchange of knowledge and skills between the mentors and mentees in the development of engineering teaching.

Gilles and Wilson (2004), in their study of 25 mentors in Missouri, find that mentors learn how to work with adults, how to 'read situations' and their mentees, when and how to challenge mentees' thinking, and how to make tacit expertise visible and conscious. It is concluded that a lot of mentoring is learned by engaging in it and that it is a learning process that takes time, i.e., years rather than months (Koballa, Kittleson, Bradbury, & Dias, 2010). In another study, Orland-Barak (2001) uncovers the learning and evolving competence of two Israeli mentors as they develop their expertise over time, partly by contrasting the practice of mentoring with the practice of teaching children. In a similar study from New Zealand, Langdon et al., (2014) show how mentors learn and develop their mentoring, for instance, by changing their conversational strategies to more co-constructivist approaches, or by viewing themselves more as "learners" than "problem-solvers" or "tellers".

Researchers have emphasized that the mentoring process requires that teachers engage in learning by building a sense of community (Sergiovanni, 1994; Sumison & Patterson, 2004). Successful community building, in this respect, provides teachers the opportunities to develop dispositions and abilities, strengthening their capacities to grow personally and professionally (Kochan & Trimble, 2000). Collectively, these changing views of mentoring and teacher learning require corresponding changes in the way individuals think about themselves, their relationships,

and their place in the work environment (Patton et al., 2005). An established CoP at Tumaini leverages the benefits of a community and on-going professional development of the mentors to take part in the process productively.

4.3.2 Situated learning perspective to mentoring

Teacher development occurs in many practice situations. With its emphasis on the relation between knowledge and the conditions in which it is acquired and used; a situated perspective continues to offer a compelling framework for this study of teacher development through mentoring. This perspective draws from sociocultural theories to emphasize the social and situated nature of learning (Lave & Wenger, 1991). One tenet of situated perspectives is that the individual, the activity in which the individual is taking part, and the environment are one whole unit of analysis (Rovegno, Chen, & Todorovich, 2003). In the case of mentoring, the teacher (individual), the mentoring process (activity), and the school context (environment) are all critical and cannot be ignored. Therefore, Rovegno et al. (2003) suggest that researchers must consider, at a minimum, "the individual teacher (including the teachers' biography, values, goals, and capabilities); the act of teaching; and the physical, social, and cultural school environment" (p. 296).

In order to examine the nature of learning, researchers have used situated perspectives to study the role of mentoring through apprenticeship. Lave and Wenger's (1991) conception of situated learning is based on anthropological studies of apprenticeship in a range of societies and occupational contexts. Descriptions of apprenticeships among midwives, tailors, butchers, and other similar occupations provide examples of how learning in practice takes place and what it means to move toward full participation in a community of practice. In these instances, engaging in various apprenticeship roles facilitates learning through "legitimate peripheral participation" in a community of practice. Legitimate peripheral participation occurs within sets of relationships in which newcomers can move towards full participation by being involved in experiences or practices, thus developing new sets of relationships. Learning is legitimate because apprentice's participation matters to the community's successful performance. Learning is also peripheral because apprentices are novices whose learning trajectory is expected to result in eventual full participation as members of a professional community of practice (Patton et al., 2005). An advantage of using the concept of communities of practice is that it allows for the identification of various modes of belonging other than engagement (i.e., active involvement in mutual processes

of negotiation of meaning) that shape the learning trajectories of individuals within each community (Wenger, 1998).

4.4 Status of Tumaini's LED program during meso-cycle 3

Meso-cycle 3 started during the last term at Tumaini in 2019 (Sept-Nov). During the design and implementation of meso-cycle 3, the second version of the Localized Engineering in Displacement was on-going. The LED program was in the final phase of implementation with students starting to work on the prototypes in the five sections of primary and vocational school that were discussed in chapter 2. Before discussing the events that took place during the last term, it is also essential to highlight the significant events from term one and two to clarify the events that led to meso-cycle 3. In January 2019, with the start of the vocational school, four new teachers joined to teach the departments of electrical wiring, motor vehicle mechanics, welding and fabrication, and hairdressing and styling with a total of 16 students enrolled in the school. The four new teachers had varying backgrounds in terms of their teaching and professional experience in the field. However, they were all certified to teach vocational school according to the Technical and Vocational Education and Training Authority (TVETA) of Kenya. We held multiple discussions on the transferability and need for the LED program to be taught in the vocational school amongst the three primary teachers, the vocational teachers, the director of Tumaini, and the students. With the students, the primary teachers, and the director finding the LED program to be relevant for the school, the new teachers agreed to join the CoP and implement the curriculum. The expanded CoP group met weekly once during February and March at my house in Kenya for three hours. During the three hours, we first discussed the LED program (Figure 15), where we looked at the classes to be prepared for the next one week. During the second hour, each teacher selected a professional development topic and conducted a training session. The last hour was reserved for a group dinner and general discussion.

Figure 15. A training session on the ABCD framework of the LED curriculum during a CoP meeting

However, during the first term, some of the vocational teachers were absent on multiple weeks, and there was resistance from a few towards participation, as the LED program was not included in their job responsibilities at the time of appointment. During the second term at the center (May-July), we shifted the schedule of the CoP meetings based on the needs of the vocational teachers and conducted them at the school to avoid logistical barriers. Also, the director of Tumaini himself found the CoP to be a professional development platform and requested to participate in the group, as he was teaching entrepreneurship skills and wanted to improve his teaching practice. The involvement of the director pushed the vocational teachers to join. Towards the end of the second term, the three primary teachers (participants and co-authors in this study), made efforts to reach out to the vocational teachers and offered support. This led to the induction of the vocational teachers entirely in the Community of Practice.

During the third term (Sept-Nov), mentorship as the third phase in the professional development began, and we identified evidence-based mentorship activities as strategies for the intervention. The LED program during the third term involved advanced technical skills classes, 2D and 3D prototyping (Figure 16), and communication. By the end of December 2019, the students made prototypes for each problem area, and in the primary section, the students designed a portable solar refrigerator using a Peltier device to address the fish storage issue in the Lake Victoria region of Kenya.

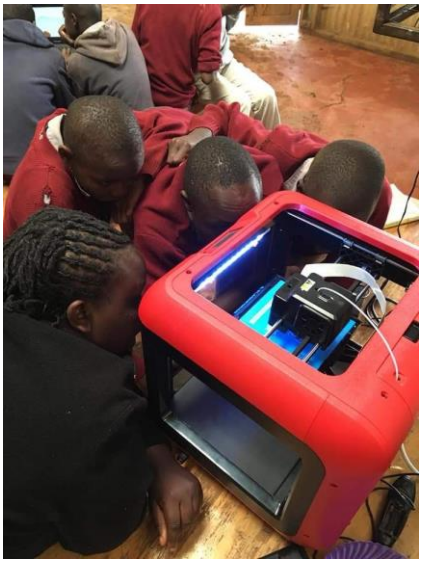

Figure 16. A 3D prototyping practical class of the primary section with teacher Ellie

4.5 Design: Intervention and Method

Researchers have discussed the components of good mentoring programs in teacher development, including communication, authenticity, encouraging gestures, honesty, trust, constructive feedback, and emotional and academic support (Beck & Kosnik, 2006; Izadinia, 2015b; Zanting, Verloop, & Vermunt, 2001). We used four key activities to encompass the presence of these components. They are peer observation, mentor-mentee pairing, lesson planning with mentors, and critical friends meeting (Figure 17). Peer observation began as a result of its reception and relevance to the practices at Tumaini since the start of reflective practice, and the critical friends' meetings continued as a result of action research intervention. These successful practices were extended in the mentoring phase. During peer observation, both the mentors and mentees interchangeably attended each other's class sessions, took notes, shared feedback, and assisted each other.

Figure 17. Teacher Ellie leading training and discussion during a critical friends' meeting with the vocational and primary teachers

Mentor-mentee pairing was done to allow each primary school teacher to be paired with a vocational teacher, and they exchanged resources and knowledge. During the lesson planning activity, the vocational teachers sat with one or more of the primary teachers and prepared their lesson plans for the LED classes.

The mentoring phase was designed for three terms to allow the newcomers to be able to go through the entire cycle of the LED program with sufficient guidance, and for them to learn and use reflective practice and action research. The mentorship intervention included the whole first term (Sept-Nov), and for two months into the second term (Jan and Feb). On March 12, the Kenyan Government announced the shutdown of schools and all educational institutions as a restrictive measure to combat COVID-19. Since then, Tumaini has remained closed for classes, and therefore the third phase of the mentorship program on engineering teaching has come to a temporary halt.

However, Tumaini is continuing to operate on its mission to protect the lives of street children from contracting COVID-19 (Radhakrishnan et al., 2020b). Tumaini is currently running a rescue and repatriation project to rescue 300 SY from the streets of Eldoret, with 51 youth repatriated back to their family and 19 who have been "rescued" and are now staying at Tumaini. For the 19 students, the teachers are running educational programs even while the school is technically closed. Recently, Sandra communicated that the mentorship is continuing, but now it

is not specific to the LED program. However, it is applicable to other teaching and learning opportunities at Tumaini that the vocational teachers can deliver, such as makerspace, robotics, electronics lab, and computer skills. In December 2019, the teachers were also awarded their certification from Purdue Digital Education for "Reflective Practice in Engineering Teaching" for the completion of meso-cycle 1, along with 8.4 transfer credit units. The certificate was handed to the teachers at the Engineering Exposition closing ceremony attended by the new teachers and the community around Tumaini.

In line with the first two intervention studies, we used a qualitative, inductive method to explore the nature of mentoring practice in the professional development of untrained teachers to teach engineering. Using the theoretical lens of Communities of Practice and Situated Learning, we analyze the data collected over the five-month TPD phase.

4.5.1 Data Collection

The study began with the critical friends meeting conducted in August 2019, where questions on challenges after meso-cycle 2 were raised and strategies for mentorship were subsequently planned. In the next five months, a variety of data collection sources were used to collect gather extensive qualitative data.

Journals:

Continuing the on-going practice of journaling, teacher journals provoked reflection on the teachers' experiences at a frequency of every three weeks. A total of 3 prompted journal entries were completed by each teacher for a total of 9 journal entries, wherein they reflected on their role as a mentor, the practice of mentorship, and its influence in the expanded CoP. In addition, the newcomers were also tasked with journals as they started the training on reflective practice. Each new teacher completed 3 journals for a total of 12 journals that were also included as data source.

Interviews:

Individual semi-structured interviews (approx. 45 min.) were conducted with three teachers, once in January, after completing the first term of meso-cycle 3. The interviews gathered more

information about the teachers' experiences with teaching engineering, their skills building a CoP, and their experience with mentorship up until that point in time.

Critical Friends Meeting

Critical friends' meetings included the meeting of the three teachers and me. We participated in a total of 9 weekly meetings where we debriefed about the teachers' weekly journal responses, engaged in detailed conversations about individual teacher experiences in the class, and planned for subsequent weeks. This allowed the chance to explore further and understand each teacher's decision-making and associated classroom challenges. From the meetings, I prepared notes and also the teachers prepared notes and reported them as minutes of meeting to the entire group.

WhatsApp Conversations

WhatsApp, a texting app, was used to serve as a flexible, real-time platform for continuous engagement and virtual collaboration. A group was formed in the app to allow the teachers and researcher to communicate virtually throughout the study.

Member Checking

Upon completion of the first round of analysis, emerging findings were shared with teachers for member checking. An online group call was organized to discuss the teachers' perception and interpretation of the results. The notes from the call was used as a data source in the final round of analysis.

4.5.2 Data analysis

Data were analyzed using thematic analysis. Braun and Clarke (2006) define thematic analysis as "a method for identifying, analyzing, and reporting patterns (themes) within data" (p.79). At each stage of the study, the data were coded using the following process. First, the data were coded based on the three components of CoP theory (Domain, Practice, Community), which also is part of the research question (Engineering teaching, Teaching, Peers). Second, within the three categories, the data were coded using the four aspects of "meaning," "practice," "community,"

and "identity," as discussed in the CoP. Third, within these aspects, open coding was performed, where a code was assigned to a unit of analysis, which in this study is the sentence (Saldaña, 2015). For example, when teachers discussed the aspects of identity through mentoring within the CoP, these statements were coded as "teacher identity via mentoring." Another example was when the teachers described events when the CoP became more reliable as a result of their ability to be vulnerable, these statements were coded as "Vulnerability – Stronger CoP."

These codes were then read, re-read, and synthesized into common categories within the three categories of domain, community, and practice. We later merged these categories to form patterns or trends in the data. These trends were confirmed across multiple data sources. The first author conducted the analysis and discussed the results at various stages with the last author for reliability. To enhance the generalizability of these findings (Huberman & Miles, 2002; Yvonna S Lincoln & Guba, 1985), we conducted member checks of vignettes of the teachers' responses and later refined these interpretations based on the teachers' (second, third, and fourth author) feedback.

4.6 Evaluation: Findings

In this section of the paper, we discuss the results of the analysis, which include the emergence of four distinct and significant themes using the structural framework of CoP. We use the three components of the CoP (Domain, Community, and Practice) to situate the themes under the specific elements to answer the ways teachers have developed knowledge, skills, and attitudes about their teaching, their peers, and engineering.

Before reviewing the themes from the mentoring phase, we briefly highlight the findings from the first and second cycle of our DBR, where teachers adopted reflective practice and action research, respectively, as strategies to improve teaching engineering. Reflective practice increased the self-awareness of the teachers about their practice and allowed them to develop meaning regarding their role as engineering teachers. As a result, the teachers established a solid foundation for the engineering community of practice and began to construct identities related to each of the three elements of CoP. Action research allowed the teachers to strengthen their practice specifically by using an evidence-based, systematic approach to conduct inquiry-based teaching. As a result, the teachers increased their sense of community by relying on each other to solve challenges, improved teaching to meet students' needs, transferred knowledge and skills to other practices, and created a repertoire that met the cultural and contextual needs of Tumaini.

4.6.1 Theme 1: Engineering CoP is a platform for equality

Theme 1 is broken down into two sub-themes that each distinctly frames how the engineering CoP is viewed and used as a platform for equality by the teachers.

Sub-theme 1a: "Oldtimers" recruit newcomers for collective organizational benefit

In situated learning, participation is central; it is through participation that identity and practices develop (Handley, Sturdy, Fincham, & Clark, 2006). As Wenger suggested, participation refers "not just to local events of engagement in certain activities with certain people, but to a more encompassing process of being active participants in the practices of social communities and constructing identities in relation to these communities" (Wenger, 1998, p. 4). Thus, participation is not just a physical action or event (Clancey, 1995); it involves both action ('taking part') as well as connection (Wenger, 1998, p. 55). To some extent, variations in the degree of participation (as felt by individuals or recognized and labeled by other members (Handley et al., 2006)) are explained using qualifying terms: peripheral (for newcomers permitted to participate to a limited extent in simple, relatively discrete tasks and relationships); full (for "Oldtimers" who participate at the core of the community); and marginal (for participants who are kept at the periphery of the community (Wenger, 1998, pp. 165–172)). An example of the latter from situated learning (Lave and Wenger, 1991) is the case of the meat-cutter apprentices in US supermarkets. Here, the 'commoditization of labor' (Lave and Wenger, 1991, p. 76) transformed apprentices into cheap labor who were put to work in ways that denied them access to the activities of a mature practice.

Full participation may be denied to novices by influential practitioners, as was the case within the meat-cutter community. Constraints on newcomers may be most persuasive if the oldtimers threaten to 'transform' the knowledge and practices of the existing community since that knowledge is essential or 'at stake' to the full participants who have invested in it (Carlile, 2004). However, in the engineering CoP at Tumaini, the three primary teachers were facilitating recruitment of newcomers, instead of being threatened. Because the teachers realized the benefits of the CoP and the engineering program, they were developing into advocates for the engineering group and actively recruiting others in the organization to collectively benefit from it.

For Sandra, the LED program at Tumaini reconfigured her attitude towards engineering and shaped her view that the problem-solving approach and understanding of engineering could

benefit everyone at the center irrespective of their profession and background. During the final interview, Sandra mentioned:

> And now, learning to change your attitude towards engineering, that I think is a huge milestone that we have covered as staff, that now, anyone can become an engineer. I was talking to Chuck (at Tumaini) on Tuesday, and he said, "Oh, from your engineering training, like there are areas I want to get a certificate too."
>
> So, he was already thinking of where now he can come in because he doesn't teach classes. And I was like, "Yeah, it's open for everyone because it's not the engineering that you have grown up knowing, but it's the simple process that you do from identifying, you have a problem in this, and all the way to finding a solution, that is what we're doing in Tumaini, that is the engineering that we're doing." (Sandra, Final Interview)

Similarly, Ellie actively identified herself as an engineering teacher and talked about the benefits of the CoP group to her colleagues.

> I remember when Carrie (hairdressing teacher) came in the beginning, she is my neighbor too. And she asked me, "What do you do in Tumaini apart from teaching language?" Oh, "I teach engineering. It is also a certain group you can join too. If you join it is very good. It has opportunities. You can teach engineering; you can do a lot." And my goal into 2019 was I wanted more people in engineering. I convinced Michael (electrical wiring teacher and deputy principal of vocational school at the time) and then both of us wanted it to be a bigger circle because me, you, William and Sandra, we used to share ideas, do training and grow. So, I wanted others too to do that. (Ellie, Final Interview)

As a result, Ellie's efforts motivating and recruiting Carrie to be part of the CoP resulted in a full year of Carrie's engagement in the LED program and become the newest member of the Untrained Teacher Professional Development Program in 2019. As a final activity for the year, the teachers were prompted to reflect on the meaning of engineering and their experience. In the final journal, Carrie noted her negotiated meaning of engineering as a problem-solving technique and that anybody can learn and apply it in their practice.

> "To me I think from my experience the whole year participating in the engineering program, it is simply the art of solving problems using different techniques and approach depending on the problem being looked upon, also have learnt that engineering is not only for specific people who have pursued only engineering course but also it is applicable to all areas and anyone can apply to solve his/her problem to come up with appropriate solution that is durable" (Carrie, Journal, Jan 14, 2020)

In addition to her immediate colleagues, Ellie was convinced that the director of Tumaini should join the group. So, she actively engaged in discussions with him on how he could benefit from the CoP. She also foresaw that if everyone at Tumaini participated in the CoP, they would be able to develop a mindset of equality and learning irrespective of age, position, background, or

responsibilities, and such a mindset would therefore only result in the growth of the individual and of the organization. In her final interview, Ellie mentioned that:

> I would go and talk to Mwaniki (Director of Tumaini) like I give him suggestions or tell how we can do it better; he wouldn't take it very seriously or he would take it very personal. He would feel like, "Why is Ellie telling me this? Maybe She thinks I cannot do it by myself."
>
> I used to say, if you come to the engineering CoP, then you learn what we're learning, then your mind will see what we saw. It will come like equally to us. It is very, very easy for you to be able to know that, "I can be corrected." It is only in the engineering group that I was taught to be a critical friend. So, if you come, you will be taught how to be a critical friend. It has been a very good change. And it was a very big change because ... I wish even all staff can join that because it is something that if we do it on a Tumaini level, we all will become in one mindset. (Ellie, Final Interview)

In addition to recruiting, the teachers also realized the importance of reaching out to newcomers as mentors themselves. Communication researchers have noted that when individuals develop close interpersonal relationships over time, they also establish mutual respect, empathy, trust, and shared goals (Knapp & Daly, 2011). Interpersonal communication principles are closely tied to mentoring frameworks. As a result of mentorship, mentors develop insights into the importance of establishing reciprocal rapport and trust with mentees (Denmark & Podsen, 2007). Trust and open communication are at the heart of mentoring. Therefore, Pitton (2006) notes, “interactions between mentors and mentees must be based on trust" (p. 19). Open communication builds trust. In turn, trust promotes open communication. Sandra discussed that she had to change her approach, engaging with the new teachers to support them and help them participate more in the LED program and the CoP by starting an open communication. Sandra said:

> Be accountable first and reach out more to people. Last year, with the new teachers who joined the COP, there was quite a challenge with them, with the classes, "How do we do this? What do we need to do?" and all that. And looking back, yes, I did step in a few times to help, but I think we could have done a better job. When I was preparing for my class, I should have informed the others in terms of allowing to see, preparing for my class, so doing my journaling or reaching out more, "What have been some of the challenges you're having in class? How can I help?" I think those are the questions that I didn't ask. So, mine was, "You have a class tomorrow, have you prepared for it?" They're like, "No." "Why?" "I'm really having ..." "Talk to Dhinesh" or "When you find time, just come. If you get stuck, let me know." And I don't think those were the right questions to ask them.
>
> Now, it's more on, "Where are you at? How can I help?" or "I'm preparing for my class, I just don't want to prepare on my own, so you can join." And also keeping people in check, yes. I think that for me, will work, and also allowing people to ask me questions about my preparation in class, and allowing more teachers to observe my class as I observe theirs. (Sandra, Final Interview)

To Sandra, the changed approach benefited her as much as it helped the new teachers in engineering. The role played by the oldtimers was clearly reflected by the newcomers in their reflection journals. For example, in the final journal when prompted to think about what part of the CoP's activities to be retained, eliminated, and changed for the coming year, Carrie noted the mentorship as an activity that must be retained and it helped her a lot.

> "We should retain the old crew (oldtimers) as mentors since they have been of great help to us the new CoP teachers (newcomers) in preparing us to handle our classes most of the time and that has made our work easier and interesting to do. In the program we should do more often that the oldtimers should join us in our classes to see the progress and also see if we are continuing to do it right and we are improving by giving comments (feedback)." (Carrie, Journal, Jan 14)

Unlike the meat-cutter community explained by Lave & Wenger (1991), the mature members of the engineering CoP at Tumaini facilitated efforts towards equality within the CoP by enabling everyone without bias to participate in the CoP, starting open communication, building trust and adopting methods to ensure full participation by all the members irrespective of their maturity level in participation. We discuss the concept of equality here as described by the teachers themselves, which are specific to access of the engineering community to everyone, and eliminating perceptions based on profession, background, and hierarchy.

Sub-theme 1b: Engineering CoP equalizes power

The community of practice is a social learning theory. When learning takes place in a social system, issues of power are at the core of the perspective. In theory, a community of practice could be a harmonious, homogeneous community. However, the theory's explanations of participation and trajectories of members in the periphery, full, or marginal paths would become meaningless without the existence of power (Wenger, 2010). For example, maturity levels of members, and the decisions of who qualifies as competent to be able to even undertake participation are all questions of power. The power dynamics of learning and community also take place in a landscape of practices. Continuous involvement in the community of practice offers legitimacy as a means of socially demonstrating competence and influencing practice. Such legitimacy gives power to the members to structure the community in contextually relevant ways. Data analyzed in meso-cycle 3 showed that power was critical in the engineering CoP. However, the teachers used the power they gained through the legitimacy of the CoP to equalize themselves in regards to the others in the group who held more power in other contexts, mainly the director of Tumaini, and the first

author as an engineer, researcher, and a facilitator in the group. During the final interview, Ellie said:

> And despite the management (the director) being there at the top, and me being maybe down here, and there are so many people in between, I can break this bridge by CoP. Only on CoP I talk to him (the director) and tell him, "I think if you do this, this will happen, this will happen. Then prepare for class like this." you know in these times, the CoP has given me a lot of experience and it brings me down to earth and I can even talk to you and you have PhD. I only have a degree.
>
> Dhinesh:
>
> I don't have a PHD yet, but-
> Ellie:
> Yeah, you see. And you're pursuing your PhD and we can see the idea. I can tell you something right about anything even tell when you are wrong. It makes me feel like I'm equal to everyone. It is just a group that makes people feel like all of us are the same, yeah. No one is treated special in that group. I can chair the meeting today, tomorrow you chair the meeting, the other day someone else chair the meeting. So, it makes us feel like we're all equal. There is equality in that. (Ellie, Final Interview)

For Sandra, my role as an engineer and a researcher signified power, and she felt that through the CoP, I was able to realize that I am equally learning along with the members, mainly the contextual and cultural knowledge. She mentioned during the interview:

> We're all learning, so sometimes when there's that, for lack of better word, let me call that gap between your level of where you are in engineering and where we are at, and so when we are explaining to each other, in our language that we understand, using the examples that we have, that are very local, it gets easy. Sometimes that's why you find even in COP, sometimes someone switches to Kiswahili to explain to someone, and then you're like, "Uh, now, I get it." Because we're familiar with our environment-
>
> ... we're also familiar with the type of terms meaning like the way I'll explain something to Ellie is not how I'll explain it to Patrick (motorvehicle mechanics teacher). But now, when you're there, the way you're explaining it, you're explaining to all of us, so I think that's where the differences come. It's a good thing because in those small groups, you're able to acknowledge that yes, "I may have the knowledge on engineering or, I may have the skills and all that", but the main idea is for you to understand, how we will understand, and so whichever way we get to understand, works either way. (Sandra, Final Interview)

The contextual understanding of representing subject matter using culturally relevant examples, analogies, and other teaching methods is essential in every learning environment. Therefore, Sandra's view about the community being able to do that to each other became another step towards a more equal level for sharing resources and knowledge, without the power of the facilitator during the training or discussions that might otherwise threaten their engagement.

From both these sub-themes, we can see that the engineering CoP has transformed into a platform for equalizing power relations and resource-sharing. The teachers have made it open for anyone in the school to engage, participate, and gain knowledge and skills, moving towards

minimizing or reshuffling power differences using the notion of "critical friendship" within the community. As the teachers become more secure and confident in their abilities and identities, they reveal more of themselves and express "an attitude toward each other that is honest, open, spontaneous, and nonjudgmental, and based on equality rather than superiority" (Beebe, Beebe, & Redmond, 2000, p. 7). This particular outcome that has developed a means of welcoming newcomers and mentoring them allows for the CoP and the TPD to generate a more shared understanding of the practice and sustain it (Wenger, 2010).

4.6.2 Theme 2: Recognition of expertise through mentoring validates mentors' engineering teacher identity

As the teachers immersed themselves in engineering teaching, participating in the CoP, and mentoring newcomers, they felt recognized for their expertise and identity as engineering teachers. Wenger (1998, 2010) theorized that as members negotiated participation in the broader systems of social learning, three different modes of identity could position learning in the landscape of practice: Engagement, Imagination, and Alignment. Engagement, as the most immediate relation to practice, involves participation and development of identity as a participant or non-participant in the CoP. Imagination involves constructing an image of the world regarding the practice and associated connections of the world to understand if one belongs in it or not. Alignment is a "two-way process of coordinating perspectives, interpretations, actions, and contexts within and outside CoP of where it is situated, such as the organizational leadership, so that the actions have the effect that is expected" (Wenger, 2010, pp.184-185). The engineering teachers demonstrated various modes of identity as they participated in the mentoring phase.

According to Beauchamp and Thomas (2009), the dynamic and continuously evolving nature of teacher identity is shaped by an examination of the self in interaction with others in a professional context. Ellie felt her identity as an engineering teacher was validated and appreciated when the newcomers recognized her expertise in delivering the LED program, as well as when she was able to reflect on that moment critically. During her final interview, she said:

> So, it was so positive to me that in as much as it was difficult, at the end of 2019, I gained a lot. I learned a lot. And I can comfortably say that I achieved what I wanted to achieve in teaching engineering class last year. It was a bad start for me, but it was a very good ending because I would teach, I would understand. Sometimes people were coming and asking me,

> especially people from the vocational, they came and asked me, "We heard you did your class, your class today went for two hours. And how did you manage? Two hours, what were you teaching? Can you share?" And, I will go like, "Well, you start with class preparation and journaling…."
> There's nothing so good to a teacher than having a feeling that someone is consulting, and that person is not a student. It is a step ahead for me. Because you cannot come to ask me something that I don't know. So, if you come to ask me something that definitely means you have seen it in me, and you know I can explain it better. So, whenever someone comes and ask for my journal or ask for me to explain I feel like I am a step ahead because I know this. It makes me feel like I am doing now what I wanted to do, teaching and getting answers to people. It makes me feel good. It makes me know I am a good engineering teacher. (Ellie, Final Interview)

For Sandra, by mentoring, she changed the newcomers' perception of engineering, which was similar to her own at the beginning of the LED program. Upon mentoring to alter the newcomer's attitude towards engineering, the newcomers recognized the efficiency at which Sandra was able to perform in her roles due to engineering. This change in perception of the newcomers was a success measure for Sandra, and she felt her identity as an engineering teacher was validated.

> And the mentoring part for me, I think specific to engineering has just helped number one, to just deal with the perception towards engineering, because it's not the math, the course work of constructing roads and all that, but it's the simple things and solving problems, existing problems. Just using a method, a design that has instructed and just learning that and applying it in other things, all the way to getting your solution, that's simply engineering. And when I mentor that to someone the mentoring part, you know that person actually saying that you are actually using the best in almost everything that you're doing by doing engineering, and that I can also be able to use that. That is good. Because of that I know the person has taken it (engineering) and can do good work. And, I know I am doing it right. (Sandra, Final Interview)

From both these quotes, we can see the different modes of identity that the teachers have identified themselves. Ellie has developed a sense of becoming (identity) through engagement and imagination. Ellie's engagement with practice allowed her to be recognized and further reflect on that recognition and imagine herself as an engineering teacher. Sandra has constructed identity through alignment by enabling her mentees to have a coordinated understanding of the practice that will allow synergized action and outcomes.

4.6.3 Theme 3: Sense of Vulnerability Enables Sense of Belonging

During meso-cycle 2 (adopting action research), the three teachers demonstrated that a sense of vulnerability was vital to have open conversations and, in so doing, trust each other to participate fully in the CoP. With the induction of the new teachers, the prevailing status quo was initially threatened. The three teachers found that the dynamics of the group changed, and the CoP faced challenges in being fully functional. The teachers identified that the cohesion already developed amongst the three teachers and the researcher made the new teachers feel alienated, though unintentional, and the matters became severe to the extent that communication of any kind stopped amongst the teachers. Sandra observed this and reported it during the final interview. She said:

> Because some people are feeling like they're being left out and you see that it was not intentional, but it had other consequences that made one feel like left out. You're so used to doing this with this person (amongst the three teachers), and so the other person (new teachers) now is onboard but is feeling quite left out until it got really out of hand. Yeah, after three days of people not talking to each other, and it was really affecting even our work here in Tumaini, because now, we got just the CoP matter to figure out, and we had to sit down and talk about it, and it's something usually we don't like talking about it. As Kenyans we just avoid talking about these issues. (Sandra, Final Interview)

Sandra reported further that the ice breaker to this challenging situation was for one person to be vulnerable and then for everyone to accept the stance that everyone is learning within the CoP. According to Bullough, Jr. (2005), “to teach is to be vulnerable, and so it is with mentoring” (p. 37). Managing vulnerability is a large part of learning to teach and being active as a teacher and, again, so it is with mentoring. Sandra realized that the moment when oldtimers and newcomers were vulnerable in front of each other, they once again became a community.

> I think the main thing that helped us all is like, "Now, let's put aside every other conflict and live with humility." because when we're here, Ellie is an expert in her department, Sandra is an expert in her department, Patrick is an expert in his field. Like we respect that, that when it comes to matters to do with vocation school, Patrick is the guy. When it comes to things to do with beauty and hairdressing, Carrie is the person. And you see so it became ... I think at the beginning, it was we're coming as those professions, instead of just coming as people who are learning. And the fact that we got to a point where we saw that we really don't know what to do to keep it going ... And getting to a point where someone started, they're like, "I need help." That I think it was one, like it was let me say the breaking point of now, "I still got to learn teach, to learn from one another and to assist how we can." I think that was major incident during this time. (Sandra, Final Interview)

As a mentor, managing one’s vulnerability is essential to create the conditions and to

provide the support to assist a beginning teacher in learning to manage his or her weakness, to get beyond self-concerns, to become or remain teachable, and to maximize growth (Bullough Jr., 2012). Despite a mentor's hesitancy, it is necessary, as Page, Rudney, & Marxen (2004) suggested, for them to position a beginning teacher in a place where there is no avoiding the confrontation with limitations, especially given the importance of the mentor's charge to protect the students and collective institutional goals.

Sandra pushed Carrie (hairdressing teacher) towards understanding and changing her preconception that still as a mentor, Sandra could learn from Carrie. Carrie and other vocational teachers, as formally trained technical teachers, have gone through training in technical drawing and other vocational skills that the three untrained teachers lack. Therefore, Sandra's discussion that mentoring is a two-way learning process helped Carrie to see the collaboration as mutual and meaningful.

> Removing the barrier that was there between the older team and the new team, that has really helped. Because for example, when we are preparing for now that class for technical drawing and me admitting I have no idea what technical drawing is all about, and I remember Carrie was like, "You have never done these things before?" And I'm like, "Actually, yeah." "So there is an area that I have an attribute to help you?" And I was like, "Yeah, just because we've been teaching you , it doesn't mean that we know everything.... The materials are different every year, and we're just continuing planning and learning. Just because we have been learning the two years before you guys does not necessarily mean that we are now really experts, that we are done learning." And because of that, there is now that sense of, "We're all learning." so there's no need of saying that ... or rather isolating yourself with that, "I was here two years before you guys, so I know it." But being there and also learning to some extent you see that, "Well, if they're also learning then you may not have it all, so you're also learning." (Sandra, Final Interview)

William also shared such mutual learning and engagement during his final interview.

> Mentoring has been a good experience for me because I understand how someone can understand certain concepts unlike for me. So even being a mentor to other teacher, it has been a very good experience for me because you stay with ... You go and see a concept with your colleague. So you tell him how you will teach this one, and when he is teaching, you can observe how he is teaching and learn from them their approach. Patrick comes and asks me how to teach this one, and I tell him, then I go to his class and see how he does the technical classes. Because you know they know those topics very well. (William, Final Interview)

For Sandra, it was equally important for her to confront her own vulnerability as it was to make changes to improve the actions and outcomes of the group. She acknowledged where she

could grow and immediately addressed the gaps to ensure everyone in the CoP was able to have a sense of belonging and support.

> And for me, I think it was acknowledging that I was in the wrong for not including everyone and allowing everyone to say what they think about it. So, people were saying, "We feel left out." others were saying others don't participate as much. So, you see, the normal issues with a team, there are those who are always proactive and there are those who'll just wait until you ask you them, and well, you needed to sit down and resolve it.
>
> And moving on when we were preparing for the classes, we were informing everyone, but I think we were posting it even in the group, that, "Oh, we're doing this and this, so if you're available, you can join." Like, "Today in the afternoon, we're meeting to review the content for tomorrow's class, if you're ..." so that everyone knows that this is happening so if you want to join, you're welcome, we can't force you, but also if you don't want to, you can't say that you were not told. So, I think I'd say CoP has, it has really, really kept me on my toes, and kept me in check, and humbled me to know that I really don't know it all. (Sandra, Final Interview)

The efforts made by Sandra was reflected in the newcomer teachers journal. Frankie, the welding teacher faced a tough time when she couldn't accomplish the goals of the classes she was teaching and were deeply disappointed. However, through Sandra's initiative to reach out and help, Frankie was able to develop new understanding of teaching the engineering program by observing the old teachers' classes. In her prompted journal for the prompt on feelings faced by the teachers while confronting challenges, Frankie noted that:

> "I really feel discouraged and disappointed when I faced some challenges in teaching engineering. I also feel ashamed and see myself as if I am not doing the right thing. I finally addressed this feeling by using a few different techniques and I can see it has brought a lot of changes and positive perception in my teaching. One of the main ways I did was when Sandra said in WhatsApp 'come to our class we are going to teach today", I went and observed the old teachers when they were teaching and used those skills when I am teaching and it has made me to enjoy the teaching and make my students in the course to be positive." (Frankie, Journal, October 1, 2019).

Though the three primary teachers have had two years of experience with the LED program, the dynamic nature of the curriculum includes some content that changes based on the needs identified by the students and teachers. Therefore, the teachers will continue to be on a learning trajectory when it comes to the LED subject content. Understanding the nature of the program and accepting to be a continuous learner improves the self-agency of the teachers (Lasky, 2005). According to Wenger (1998), the participants in a community, at whatever level of maturity they are (i.e., peripheral, full, or marginal), contribute to the community in a variety of interdependent ways that become material for building a member's identity. Therefore, the identity

of membership in the engineering CoP is also contributed to by the various ways the teachers experience vulnerability and tackle it.

4.6.4 Theme 4: Proving Self-Worth – Main Coping Strategy for Engineering Teacher Identity Development

The teachers noted multiple times during all the three meso-cycles about the perceptions and stereotypes of an engineer in Kenya concerning gender and the realities of women in engineering programs (Refer section 3.8.2, and 4.9.4). To back up the teachers' claims, we also present here evidence about the overall status of Kenyan women in engineering. An article published in 2017 based on data from Engineers Board of Kenya, states that only 5.4% of the registered professional engineers were women, and 8.8% of the listed engineering graduates were women in the country (Engineers Board of Kenya, n.d.; Ondeiki, 2020). Globally, Women face stereotypes at a young age and low funding later in their careers (UNESCO, n.d.). Representation in the local flagship engineering university near Tumaini is low (13.9% women in the School of Engineering) (Madara & Cherotich, 2016). Although women are underrepresented in engineering, there are also notable high achieving examples of women in engineering leadership in Kenya and the region, illustrating the importance of women in engineering as role models (Ismail, 2017), for both men and women students. Therefore, women in formal engineering programs in Kenya must confront stereotypes and gendered assumptions while engaging in the program. Further, no available literature on women in engineering in informal spaces leaves us challenged in understanding the beliefs, perceptions, women in informal areas face as they engage in engineering teaching and learning.

Ellie, during this meso-cycle, actively discussed the challenges she confronted, such as questions about her credibility to teach engineering and the influences of it on her engineering teacher identity development. For her, the problem started at home. Ellie's brother, an engineer who went through the formal university education system in Kenya, found it hard to believe that Ellie was teaching engineering at Tumaini, in particular when he heard of engineering subject matter terms that he was not familiar with from his education. Ellie shared during the final interview:

> Yeah, for me. I remember when I started doing the engineering, my brother would see me at home preparing for the class and I'd write engineering, used to say, "Engineering design process." And my brother did civil engineering at the university and he's, "There's nothing

> called engineering design processes," I was like, "Yes, maybe there is nothing like engineering design process to you but there is engineering design process in Tumaini." (Ellie, Final Interview)

Teachers' identity is reshaped continuously, and the narrative they hold of themselves is also affected (Dell'Angelo & Seaton, 2016). Teachers' view of themselves is challenged and transformed through interactions that force teachers to confront their assumptions (Alsup, 2006). From Ellie's case, we see that the teachers face not only their own assumptions but also assumptions of others while constructing their identity. Nias (1999) suggested that "the desire to protect conceptions of the self, results in teachers going to considerable lengths to protect their sense of individual identity" (p. 225). The individual identity that the teachers will construct, is based on the kinds of coping strategies chosen by them. Coping is making an effort to manage a troubled person-environment relationship and implies that teachers can sense and evaluate these tensions (Admiraal, Korthagen, & Wubbels, 2000). Pillen et al. (2013) presented from their work that coping with tensions in teacher identity development is emotionally difficult for early career teachers. Nias (1996) also argued that the emotional reactions of teachers to their work are connected to the views that they have of themselves and others. Ellie, motivated by proving her self-worth, demonstrated problem-solving coping behavior (Admiraal et al., 2000) when faced with the challenges of credibility to teach engineering from her family members. By participating in the CoP and the LED program, Ellie earned her certification on Reflective Practice, which authenticated her as an engineering teacher.

> And it was complex for them to understand if I tell them I am teaching engineering. So, in as much as I'm teaching, I wanted to prove to people, especially my family that I can teach engineering. They have known me of someone who is scared of physics, chemistry, maths, and engineering is all about those complex things. And my brother was like, "oh, Okay! (Sarcastically)"
>
> I remember when I took the certificate home, the one that we got first and the one that I took yesterday, yesterday in fact he (her brother) told me, "Congratulation. So, this is serious." I was like, "Yeah, see "reflective practice in engineering teaching." So, I CAN teach engineering. (Ellie, Final Interview)

The tension on questions of credibility for Ellie was also faced in her workplace. She also shared:

> Patrick (vocational teacher) kept on asking, "Why are you doing engineering? I have gone to university, what is engineering. Are you sure you're doing the right thing?" So, it was very difficult for me to explain to them at the beginning. (Ellie, Final Interview)

Research in STEM identity suggests that identity development is a result of strong associations or affiliations with the field (Morton & Parsons, 2018). These associations are exhibited by competence, efficacy (Adedokun, Bessenbacher, Parker, Kirkham, & Burgess, 2013), and confidence in STEM content and procedures; and, they are also confirmed by individuals' STEM performances and recognition of those performances from STEM professionals (Morton & Parsons, 2018; Thiry, Laursen, & Hunter, 2011). From our discussion above about the limited number of women pursuing engineering, Ellie expanded further on the cultural perceptions and how it affected her job roles and responsibilities at Tumaini.

> For other people, it seems to be difficult and for Kenyan culture, it is very, very weird for a woman to be an engineer or to teach engineering. That's why you will find in Tumaini around basic accelerated learning, Mr. Kinyenji or William is teaching mathematics and not Ellie. It doesn't mean that I cannot teach mathematics, I can teach mathematics, but they feel like I should teach English and Swahili.

It was not until the start of mentorship that Ellie was able to develop an identity as an engineer and an engineering teacher. Mentorship allowed her to demonstrate competencies as an engineering teacher and imagine herself as an engineer (images of the world relating to the practice, as discussed by Wenger (2010)), thereby proving her self-worth and constructing an engineering teacher identity.

> So, teaching engineering, to some people, they don't believe it. I didn't believe it at first and it is just when I mentor someone in engineering, it makes me feel like I'm wearing something like engineering dust coat, closed shoes, and it makes me feel so good. It's so good to be a pro, let me say a pro on something that you thought you would never teach. I never dream of teaching engineering. But now I have proved to myself and to others.

Theme 4 is derived from the experiences shared by Ellie. Amongst the three teachers, it was only Ellie who shared these experiences. However, considering that there were only two women teachers amongst the participants, we find it significant to discuss the reshaped identity of Ellie as a theme. We also note here that Sandra also discussed similar tensions experienced as related to her identity as a woman delivering engineering during meso-cycle 1 (refer 3.8.2). However, the data available currently did not reveal Sandra's coping strategy. Therefore, we discuss theme four as a single case result, and Ellie's experience shows that proving self-worth was a positive problem-solving coping behavior that allowed Ellie to construct an engineering teacher identity.

4.7 Discussion and Implications

In this study, we presented a detailed account of our approach and rationale in initiating mentorship as a teacher professional development strategy to expand and sustain the outcomes of an established engineering Community of Practice. We investigated how untrained teachers developed knowledge, skills, and attitudes about their practice of teaching. The meso-cycle 3 of this DBR study has shown that mentoring has enabled the teachers to enhance their development as engineering teachers by:

(i) Realizing the benefits that the engineering curriculum and engineering CoP has to offer to not only the teachers, but to the entire institution, and actively recruiting new members to learn and grow in the CoP

(ii) Developing legitimacy by continuously participating in the practice of engineering teaching and mentorship, which further equalizes power within CoP

(iii) Validating their engineering teacher identity by mentoring newcomers to take synergized actions and by then seeing expected outcomes

(iv) Exhibiting and accepting vulnerability via mutual engagement and engaged diversity to establish a reformed sense of the expanded community

(v) Adopting problem-solving coping behaviors in response to threats to identity development and using mentoring to demonstrate competence

Mentorship was initiated as a strategy to address the specific issues brought out by the teachers during the analysis stage of the previous meso-cycle. We discuss the study's results by answering those questions.

1.) How do we become inclusive and open for the new teachers in the CoP?

Knapp and Daly's (2002) suggestion that individuals develop mutual respect, empathy, trust, and shared goals as a result of interpersonal relationships over time was key to answering this question. The authors' list of developmental elements is at the heart of inclusiveness and being open within a CoP. CoP theorists and practitioners have discussed that the oldtimers (matured practitioners) of the group mentor newcomers to acquire the skills and dispositions needed for serving the community's shared goals (Denmark & Podsen, 2007; Lave, 1991). The literature indicates that mentors can assist those who are new to practice (Feiman-Nemser, 1996). Themes 1 and 3 of our results demonstrated how teachers' efforts and experiences adopting mentorship

created an inclusive space for the newcomers. The three teachers in the study were actively connecting with colleagues in the institution to join their shared learning and shared purpose. The understanding that the teachers had regarding the benefits of the engineering program, including that it extends beyond the students learning and that it creates more opportunities for the individuals and the institution, was primarily the motivator for teachers to include new members willingly. Such a shared understanding to expand the benefits to fellow members helped teachers address the challenges they faced during the process. Vulnerability, once again, served as the push factor to overcome barriers and form a sense of community. Both during the formation and the expansion of CoP, the results show that sense of belonging stems from being vulnerable. Therefore, mentoring has enabled the three teachers to empathize with the newcomers and transfer their learnings from being vulnerable to the larger CoP, thereby making it an inclusive and open group for the new teachers.

A situated perspective of the context can help in better understanding the results. Besides the engineering teaching being a new practice to the teachers, the practice of educating and rehabilitating street youth is also new to most members of Tumaini. Except for the Director and the caretakers at Tumaini, all the staff are new to the practice, with experience ranging from 1 to 5 years. Also, due to a lack of proven models of working with street youth, the institution is designing its own models and learning along the way. Therefore, teachers are intrinsically motivated by the need to learn and meet the needs of the students. Our prior research from the LED program has also discussed teachers' intrinsic motivation to learn to serve better the needs of their students (Radhakrishnan & DeBoer, 2018). This intrinsic motivation is a crucial factor for teachers' vulnerability and mutual engagement.

2.) How do we (oldtimers) demonstrate our capability?

We discuss the question of demonstrating capability using the notion of identity development of the teachers. The literature points to emotion as a significant and ongoing part of being a teacher (Flores & Day, 2006). Teachers experience an array of contrasting emotions in their practice. Kelchtermans (1996) reported that teachers feel vulnerable when their professional identity and moral integrity are questioned by policy changes, parents, and colleagues in light of unrealistic expectations, assumptions, or their failure to support the achievement of students. Similar experiences of the teachers in the study being questioned on their credibility to teach engineers by their parents and colleagues enabled teachers to reflect and construct their identity.

Problem-solving coping behavior allows teachers to confront moments of vulnerability. However, mentoring new teachers has shown that it leads teachers to negotiate meanings of their capability and demonstrate competence as a skilled professional, which results in the construction of identity. We use Wenger's (1998) three modes of identification: Engagement, Imagination, and Alignment, to explain the teacher's demonstration of their capabilities.

All three modes function both inside the engineering teaching practice and across other practices. The engagement was typical of the teachers participating within the engineering CoP to mentor the newcomers on the engineering teaching and assist them to participate and move from the periphery to the center of maturation. Imagination was enabled via mentoring newcomers and developing images of the self in relation to that of engineering identities common around the world (like a civil engineer in a safety helmet, or a technician in a shop floor). Finally, mentorship synchronized the actions and understanding of the group to align the efforts towards common goals of the engineering CoP, which is to improve the practice of engineering teaching at Tumaini to implement the LED program effectively and equip the SY with marketable skills.

3.) How do we maintain this and make it sustainable for Tumaini?

The mentorship cycle has provided the opportunity for the teachers to experience the induction of new teachers to implement the engineering curriculum. Therefore, mentoring has become the strategy to maintain continuous professional development through inducting new members and collectively implementing the engineering program to meet Tumaini's goals. The community of practice is the platform and framework upon which the untrained teachers' professional development can be achieved through legitimate and legitimized peripheral participation.

4.7.1 Limitations

The results of this study must be understood while also considering its limitations. The results are limited to transfer based on the context of untrained teachers. The results presented are from a part of the initially intended program timeline, which has also limited the amount of data that we were able to collect from this phase. The full implementation of the mentorship meso-cycle was affected due to the COVID-19 pandemic and government orders to shut down teaching and learning activities. Therefore, the results presented here do not reflect the full scale of impact that mentorship could have on the teachers.

4.7.2 Implications

Implications from the study suggest that mentorship built on the base of reflective practice and action research as an empowerment tool to actualize teachers to construct positive identities around engineering teaching. The study also addresses the mentioned gaps in the literature discussing teacher identity of the mentors and the role of mentorship practice within an established CoP. This last cycle of DBR has addressed vital questions on sustainability, which allows the teachers and researchers to develop confidence in the untrained teacher professional development model that has resulted from this design-based research. To study the full impact of the DBR cycles and questions on sustainability, we recommend that a longitudinal study must be undertaken by researchers who are implementing or investigating continuous teacher professional development.

5. DESIGN OUTCOMES AND CONCLUSION

5.1 Design Outcomes

This study started with the following overarching educational problem of:

how can we design a long-term TPD that supports untrained teachers to teach engineering while capitalizing on the available assets and overcoming the barriers of fragility?

Over the course of the study, various analyses, designs, evaluations, and reflections indicate that a long-term TPD for untrained engineering teachers requires empowering the teachers to form and participate in a community of practice. Findings from this two-year study indicate that as compared to the phase prior to the TPD interventions, the untrained engineering teachers undertake the engineering teaching practice with confidence and comfort because of negotiated meaning, sense of community, and constructed identities. Based on these developments, it is possible to conclude that untrained teachers can be supported via an in-service, informal professional development program, overcoming contextual constraints and capitalizing on their assets, to facilitate a localized engineering program and constantly improve their practice through reflective and inquiry-based teaching.

Clearly, qualities which guided the professional development model, like a situated understanding of the context, collaborative approach towards the design of solutions, reflective and inquiry-based approach to raise instructional awareness, and recognition of competencies, helped develop the elements of the CoP (domain, community, and practice). In addition, other insights into shaping a professional development program can be highlighted based on this study. These are presented in terms of design recommendations in the following section.

One output of design research, as mentioned earlier, is educational solutions that can survive and be effective amidst dynamic complex ground realities. But, from a scientific perspective, the main output of this approach is to build and test theories of (in this case untrained teachers') learning, through design of learning tools and techniques that can survive the challenges of everyday practice (Shavelson, Phillips, Towne, & Feuer, 2003). In other words, participation in design and research activities is expected to yield intimate knowledge about the theoretical and design ideas involved in the intervention (McKenney et al., 2012). According to McKenney, Nieveen, and van den Akker (2006) such knowledge about how to build and implement

educational solutions that thrive in their target settings takes the form of design principles. Design principles are not intended as recipes for successful designs. Rather, "they are theory-based conjectures, which underpin design, and are refuted, validated or refined based on the research findings" (McKenney, Reeves & Herrington, in press).

This design-based research study also leads to design guidelines which are presented in the tables below (Tables 7 and 8). As indicated in the introduction above, the design guidelines of this specific study, backed by theory and validated by empirical evidence, offer generalized guidance to engineering education researchers and teacher development practitioners, to design and implement professional development activities for untrained teachers at alternative schools in fragile contexts. I have also discussed for a selected set of five design principles (characteristics – 3, procedural – 2) the starting stage of these principles in this DBR study, the changes undergone through interim stages, and the evolution through the final stages along with necessary evidence. These descriptions are provided to offer insights into the process that led to generation of the principles. Descriptions of the remaining principles along with the five discussed here are planned to be published in an upcoming manuscript.

The first table explicates the characteristic design guidelines. They pertain to salient characteristics of professional development that have emerged as desirable over the course of the study. The second table deals with how to implement the professional development program, or the procedures that contribute to the effectiveness of the program. The tables are organized into four main columns. The first column in each table presents salient (characteristic or procedural) themes about the professional development program which have emerged in this study. The second column presents key insights from theory and literature related to the theme. The third column entails key empirical evidence generated from the study associated with the theme. Finally, validated by the theoretical and empirical points, design guidelines are presented in the fourth column.

5.1.1 Characteristic design principles

Principle 1: Guided by the philosophy of learning as participation in a Community of Practice

Starting Stage:

The design principle of learning as participation in a community of practice was first identified in our study from the search for a theoretical framework to guide us in explaining, predicting, and understanding the phenomenon of untrained teacher professional development. At the beginning of this doctoral research, I identified several theories based on prior research in the context and from discussions with the teachers, the students, and the administration of Tumaini. For example, we explored the theories of growth mindset (Dweck, 2008), teacher self-efficacy (Powell-Moman & Brown-Schild, 2011), meaningful learning (Ausubel, 1962), technological and pedagogical content knowledge (Mishra & Koehler, 2006), and informed engineering design (Crismond & Adams, 2012) as possible theoretical concepts. However, these identified theoretical areas did not provide a comprehensive model for facilitating and understanding the TPD at Tumaini. The uniqueness of the context and the application of engineering in this context demanded a framework that integrated the local culture and contextual elements in understanding the phenomenon of TPD. For example, the local aspects that demanded a different theory of learning were the signs of fragility that influenced everyday operations, the characteristics of "street youth" requiring flexible ways of engaging them, and the culture embedded in the institutional, local, and national context that drives and sustains the activities at the center. The teachers who are not permanent employees of the center and in the past have quit from the job with short notices, added to the complexity of the context. Therefore, the TPD required us to not focus on the individual teachers rather the whole teacher community as a single entity at the center. Also, as part of the TPD that is a part of the LED program designed by researchers from Purdue University ("outsiders"), an important goal for us was to make the program sustainable and reduce dependency. Therefore, the teacher development has to be understood in the long-term and not only on an individual teacher.

Recommendations from researchers in the field of engineering education and education directed me towards situated learning. The situated perspective views knowledge as arising conceptually through dynamic construction and/or reinterpretation within a specific context (Johri & Olds, 2011). Further, as discussed in chapter 1, situated learning theorizes that knowledge is socially constructed, and learning occurs through meaningful activities that are part of a community of practice (Lave & Wenger, 1991). In comparison to the theoretical concepts explored before that theorized learning and knowledge to be changes determined only on the learner, the

situated learning theory presented a comprehensive view that learning is situated in the context of the social organization rather than as a shift in the mental structures of an individual learner. Further, the literature on teacher professional development in the region of sub-Saharan Africa recommended effective TPDs to consider teachers as social agents of change (Hennessy et al., 2015) and learning to be continuous and collaborative (Cochran, King, & DeRuiter, 1991). Therefore, we began the TPD with the philosophy of learning as participation in a community of practice.

Interim stage:

The theoretical framework of situated learning plus communities of practice provided both the structural and operational framework for this study to increase the participation of the teachers in the established engineering CoP. Meso-cycle 1 on reflective practice shifted the mere collaboration of the teachers and the researcher towards an organic formation of a CoP. The shift was evident from the evaluation that showed reflective practice to have enabled teachers to construct identities as a member of the community, of the practice, and on the domain. During the second meso-cycle, the introduction of action research, however, complicated the three inter-related CoP elements of domain, community, and practice, as the research itself became a new entity of domain and practice that the teachers had to learn and adapt to in addition to teaching and engineering. The teachers needed more time to carry forward with the research, as several uncertainties such as the expansion of the school to include a new vocational program started, and the number of students as part of the classes changed with some new students enrolling in the program as well. During the beginning of 2019, the teachers were overloaded with the changes in the center; during the first term (Jan-Mar) the second meso-cycle almost came to a standstill. However, the established engineering CoP continued due to the strategies effectively put in place from the first meso-cycle, such as the journaling and critical friends meeting. Weekly meetings continued to implement the engineering program. We understood that irrespective of the TPD interventions to follow after the first meso-cycle, the learning of teachers to implement the engineering program continued, and we were able to understand the phenomenon of teachers learning by considering their participation in the CoP. These developments reinforced this characteristic design principle at the interim stage.

Final stage:

After the meso-cycle 2, the changes at the school with the addition of new vocational school demanded changes in the engineering program and the TPD, and the most crucial change was to restart the second version of the LED program to include the new students enrolled and to train the new teachers employed. Even with this new shift in the program model, the design principle continued to be a vital characteristic. Both the actions of designing the TPD and researching it, were sufficiently fit within the framework of situated learning and community of practice due to its flexibility to not only accommodate the changes at the center but to entirely situate it as progress and next steps in the engineering CoP. For example, through legitimate peripheral participation, the teachers were able to include the new teachers without significantly affecting their professional development, the implementation of the LED program, and the development of the new teachers. Therefore, the philosophy of learning as participation in a community of practice provided a comprehensive research framework to understand the evolution of teachers undergoing TPD, make it sustainable, and integrate the situatedness of the context.

Principle 2: Guided by critical reflection of the self and the activities performed

Starting stage:

Critical reflection as a principle in our DBR study originated from a gap analysis exercise I undertook as part of the action research course I took at Purdue University. As part of the course assignment, based on my observations, I prepared a starting point analysis for research on the untrained teacher professional development (Radhakrishnan, EDCI567, Assignment #2). From the analysis, I presented a case that the teachers possessed various strengths such as experience in teaching "street youth" at Tumaini, contextual knowledge from their background and embeddedness in the local context, and expertise to facilitate classes with appropriate pedagogical methods for the youth. From the same analysis, I also identified challenges based on the data from several virtual meetings prior to the start of this DBR study. The challenges were that the teachers felt reserved and inappropriate to reach out to me for help consistently (as I was considered an "outsider" and sometimes a "donor" (refer to my positionality statement in chapter 1) to whom seeking constant help would risk appearing as "weak" and continuing to get donations). So, they assumed their role was limited to looking at the content from our engineering curriculum and

transferring it to the students. However, during the qualitative study undertaken to examine the perspective of teachers held by the students and the teachers themselves with the introduction of tablet technology, the teachers realized that the students held the teachers to higher regard as "role models" and also found the engineering classes to be meaningful with the potential to impact their career. Upon sharing the results of the study during a virtual meeting held in November 2017, the teachers found a shift in their motivation to be more involved, be intentional about the facilitation, and be willing to undergo training to improve their teaching. The minutes of the meeting report prepared on 13th November 2017 stated: "Students enjoy engineering. Teachers want to get training. Maybe have engineering projects of their own or learning of their own to teach. Action item - Identify ways to engage teachers in the development program during the break (December) and have ideas when the school reopens in January 2018."

Literature guided us on the importance of reflection and its role in teacher professional development. We identified reflection based on the recommendations from prominent scholars such as Dewey (1938) and Schön (1983). On 17th January 2018, we held a virtual meeting where I presented the concept of reflection to the teachers based on the study from Larrivee (2008) that emphasized the capacity of reflection to improve the on-the-job performance of teachers by using the reflective process for daily decision-making and problem-solving. As a first step, it was essential to critically increase awareness of their roles as a teacher, as a team player, and as an engineering facilitator, which can be achieved by practicing reflection based on literature.

Interim stage:

As presented in chapter 2, the evaluation of meso-cycle 1 resulted in identifying that reflection increased the teachers' ability to engage with each other as members of the engineering community at Tumaini and helped in constructing identities. At the beginning of the meso-cycle, we saw that the initial reflections were not in-depth and were superficial, like answering whether everything happened according to the plan and what happened. They failed to reflect on what was intended to be achieved from the class and how it happened. Based on the templates and recommendations from Feldman et al., (2018) book "*Teachers investigate their work"*, I used prompts to probe their reflections further and encouraged them to first reflect on their primary duties at the center. For example, William reflected on a day's event from his job as a social worker, Ellie, as a literacy teacher, and Sandra as a human resource manager. Further, the teachers reflected

using journals, and I provided feedback on how they can reflect deeply and be more critical. Cultural practices limited the teachers to be more critical of the self in front of their peers and also explicitly discuss and share in journals. For example, I found that the teachers had reservations in sharing the journal in the WhatsApp group chat and instead preferred to send it to me privately. However, with the discussions that continued on critical friends and as the teachers became comfortable with each other during our meetings as a result of demonstrating vulnerability, they became more friendly and critical during reflections. At the interim stage, the principle evolved as critical reflection to be performed both by the teachers themselves and using the researcher's prompts as the researcher performed the role of a critical friend.

Final stage:

Reflection continued in meso-cycle 2 and 3, due to its applicability to serve as a tool in the practices of action research and mentorship and the benefits realized by the teachers from meso-cycle 1. Journaling to provoke reflection is commonly used as a technique in action research to critically examine their teaching and serve as a data source for their analysis (Feldman et al., 2013). Therefore, reflection evolved as a critical principle to increase teacher's awareness, reflect critically on their practice and the self, and as a tool for the data source. In the final journal the teachers wrote at the end of meso-cycle 3, I prompted the teachers to reflect on the elements of the training and the engineering CoP that needed to be retained, that needed to be changed, and that needed to be eliminated. All the three teachers mentioned both the double-entry journaling activity after each class and the prompted journaling activity to be retained in the future. Therefore, in the final stage the characteristic of using critical reflection to increase awareness of the self and the activities performed by the teachers were reinforced and has evolved as a design principle.

Principle 5: Guided by opportunities to link practices and transfer knowledge

Starting stage:

The characteristic of TPD to provide opportunities to link other practices and transfer knowledge began mid-way during the DBR study and focused on transferring knowledge and skills of teaching engineering to other classes in the basic education school. Towards the end of 2018, as the teachers completed meso-cycle 1 and were half-way through the meso-cycle 2, they

recognized that the amount of time and effort that was dedicated towards the LED program and the TPD were significant. It resulted in the administration to be notified on the efforts the teachers were contributing to the engineering program. A meeting was scheduled on 7th October 2018 amongst the teachers, the director of the center, and the researcher to discuss this issue of time and effort. The administration of Tumaini expressed their views that the three teachers had other primary responsibilities in addition to engineering teaching, and it will be unfair to take their time and effort from those responsibilities (Minutes of meeting notes, October 7, 2018). However, the admin also expressed the importance of engineering and the benefits it had brought for the students, the center, and the community. The teachers and the researcher presented the progress made in the implementation of the engineering curriculum since the beginning of the teacher professional development. In the meeting all the stakeholders agreed it was important to continue the efforts to ensure long-term and sustainable impact.

After the meeting, the teachers, however, identified areas from the TPD that they believed they would be able to transfer to other classes taught at Tumaini. Therefore, the Tumaini administration requested intentional linkages be created, and opportunities to be provided through which the teachers will be able to transfer their knowledge, skills, and attitudes from the TPD to other classes in the primary school. Therefore, during meso-cycle 2, we began to brainstorm on ways the teachers can link the learning with their different practices. Discussions with Ellie revealed that she decided to use the knowledge of technological and pedagogical tools from the engineering program in her literacy classes, and William wanted to transfer the active learning techniques and technological tools to his science classes.

Interim stage:

In 2019, as meso-cycle 2 came to an end, we identified that the teachers chose the engineering design process and action research as strategies and tools to transfer their knowledge, skills, and attitudes to their practices. As a result, we saw that the teachers were not limiting themselves to link the knowledge, skills, and attitudes acquired from the professional development to teaching other classes but transferred it other practices such as their primary roles at Tumaini. For example, Sandra identified the relevance of using the engineering design approach to her role as a program coordinator to solve problems in the areas of staff training and employee satisfaction. The teachers were encouraged to reflect further on their transfer of practices through prompted

journals. Therefore, the characteristic of linking to other classes, became opportunities to link practices.

Final stage:

In meso-cycle 3 we also saw that the teachers identified the transfer of practices as an essential benefit of the TPD and presented it to newcomers as a motivational factor to join the CoP. This action deliberately undertaken by the teachers reinforced the significance of the principle and evolved as a key characteristic design principle. We posit that the untrained teachers in alternative school settings face a similar situation, where engineering will be a secondary practice in addition to their primary roles in the organization. Therefore, to sustain the TPD, it is crucial for the program to offer linkages to other practices that the teachers are part of, which will also receive support from the administration.

Table 7. Characteristics of Untrained Teacher Professional Development (UTPD) and their relation to Engineering Teaching in Fragile Contexts - Design Principles

Characteristics	Theoretical/Literature Support	Empirical Support	Design Guidelines
Guided by the philosophy of learning as participation in a Community of Practice	UTPD should be guided by the principles of social learning theories.		
	Fragile contexts, known to be low resource in terms of economic and technological wealth, are also rich in contextual, cultural, and human knowledge. Approaching learning as participation allows for entire ecosystem to be considered as a unit, and encourages building on assets in the context, rather than deficits (Ebersöhn & Eloff, 2006).	Assets of the context, the learners of the engineering curriculum, and the teachers were sensibly identified during the design of the curriculum, by means of engaging with the community as resourceful stakeholders (Section 2.2.3).	Define what the "context" is and what the "community" is with the collaborators to identify and build on local participants assets
	Professional development of teachers is an undertaking of an individual in relation with the environment, and other social factors. Therefore, learning is social and must include more than the individual as the unit of analysis (Lave, 1996).	Learning as a unit of analysis is expanded beyond the individual by adopting the situated learning and communities of practice framework in the analysis (2.6.3)	Engage in dialogues with the participants on different ways of defining and measuring learning and knowing (for example, I led a two hour session on fundamental learning theories with the group and identified situated learning theory to best define the "learning" and "knowing" as a means of participation)

Table 7. Continued

	Learning is an aspect of activity in the world, and so 'participation' ensures learning in practice and provides an actual measure of development (Lave & Wenger, 1991).	The four constructs of learning (meaning, community, practice, and identity explained in communities of practice, utilized as the analytical framework to measure knowledge, skills, and attitudes development (2.6.3, 3.7, 4.8.2, 5.5.2).	Ensure that ongoing learning is embedded into daily work responsibilities.
Guided by critical reflection of the self and the activities performed	UTPD should embrace and enculture reflection of the individual and reflection of the ways of participation in the CoP.		
	PD should allow engineering teachers to develop critical reflection skills before accumulating engineering teaching pedagogical content knowledge and other strategies (Larrivee, 2000).	Reflective practice enabled teachers to establish a sense of community through mutual engagement, and critically examine their identities. Both the results crucial to have motivation and critical understanding of practice before acquiring content related knowledge and skills (3.8.1, 3.8.2. 3.9).	Introduce reflection in contexts of comfort before transitioning to the practice under development (e.g., I did few exercises with teachers asking them to reflect on their most immediate practice, role, responsibility, before starting to reflect on the engineering teaching) Conduct kick-off workshop and introduce an array of tools that could be used during the intervention to meet the goals and engage in critical conversation evaluating them for the context

Table 7. Continued

	Critical reflection develops the ability to look at a situation and screen the filters of past experiences, beliefs, assumptions, and expectations, feelings and mood, personal agendas and aspirations before enacting a response. Teachers develop meaning of their selves, their identities in the practice, and become aware of their students and the environment. (Larrivee, 2000; D. A. Schön, 1987).	Reflection empowered the teachers with tools and skills to critically examine teaching, their student's needs, and their role in the enterprise of engineering teaching (3.9, 4.9.2, 4.9.3, 5.6.1).	Prompt critical reflection at regular intervals, and regularly evaluate the status of intervention through formative techniques such as 3-2-1 questions in journaling, and an evaluation meeting with the participants
Guided by collaboration and a learning community	UTPD should promote collaboration amongst teachers and build a learning community.		
	Collaboration amongst teachers is essential to have shared understanding, and shared experiences that encourages teachers to have open communication and trust. (Bullough Jr, 2005).	Mutual recognition of competencies, appreciating diversity, shared learning, and sense of vulnerability, critical friends' role, all of these contributed to the start of collaboration and the establishment of the long-term community (sense of belonging) (3.9, 4.10.1, 5.7).	Create a flexible system that provides framework for operations, logistics, and functions of the group Create team-building and interpersonal activities amongst the participants and with the researchers regularly (for example, we as a group usually went out on dinners or lunch and performed a team-building exercise before starting the meal)

Table 7. Continued

	Learning community of practice enables teachers to mutually engage by recognizing the own and other's competencies, develop a joint enterprise to establish and pursue common goals, and produce shared repertoire that sustains practice in the context (Wenger, 1998).		Establish a group by discussing individual goals, aspiration and synthesizing them as group goals Establish structure to the collaboration by discussing expectations for the group, and a central theme that the group will align itself with and pursue
Guided by needs of students, institution, and the teachers	UTPD for engineering teachers should ensure, the engineering program under practice meets the needs of the students, aligns with the institutional goals, and expands opportunities of the teachers.		
	PD should be informed by the learning outcomes and the needs of students such as existing knowledge, relevance to their future goals, and meaningful learning (Novak, 2002).	Analysis and exploration micro-cycle during all three studies guided the identification of needs demonstrated by the teachers, students, and the institution (3.2.1, 4.3, 5.3).	Define individual learning requirements based on what teachers express as well as what their actual classroom practices reveal
	During PD, central importance should be given to learning processes of teachers and the particular curricular and school contexts in which professional development takes place (Penuel, Fishman, Yamaguchi, & Gallagher, 2007).	Involving the teachers during the design, resulted in adoption of intervention strategies that benefitted the needs of the teachers and institution (3.6, 4.8. 5.5).	Aim to (re)design necessary learning activities as well as meet (contextual) organizational requirements necessary Identify strengths and weaknesses of the local context, e.g. organizational factors, that could impact teacher learning

Table 7. Continued

Guided by opportunities to link practices and transfer knowledge	UTPD for engineering teachers should allow and promote use of knowledge, skills, and attitudes from PD to other practices.		
	Contextually, when engineering teaching is not the primary practice of the teachers, authentic learning (Herrington & Kervin, 2007) of the domain and practice that allows for transfer of knowledge, skills, and attitudes to other practices (Wenger, 1998) that individuals find relevant are important.	Transferring knowledge and skills gained via the LED program such as engineering design process, problem-solving techniques to other practices of the teachers enable personally meaningful experience and a motivational factor to recruit newcomers into practice (4.9.4, 5.6.1).	Be explicit during trainings and discussions on the knowledge, and skills gained from engineering, and teacher professional development can be used in other practices of the individual or the institution. (For example, we engaged in multiple discussions on how the teachers can adopt learning from the LED and TPD to their other classes, to rehabilitation, social work, and program management) Encourage teachers to reflect regularly on the transfer of knowledge and skills to other practices via journal entries

Table 7. Continued

Guided by continuous professional development and sustainability	UTPD for engineering teachers should be focused on continuous, self-sustaining model (a) Communities of Practice sustain with the members becoming full practitioners, and interact with members in the periphery, guiding them to the center (Lave & Wenger, 1991). (b) Teacher professional development should be continuous and long-term (Cochran-Smith & Lytle, 2001).	Mature practitioners recruit newcomers to sustain the practice by developing deeper insights on the benefits of the learning community, realizing the benefits of the practice, and developing shared understanding of practice and actions to achieve collective outcomes (5.6.1, 5.6.2).	Encourage newcomers to shadow mature practitioners before integrating them in practice Ensure newcomers follow the same procedures that started with the oldtimers, such as discussing individual and common goals and expectation, redefining central theme. Critically discuss the purpose and role of mentors if engineering teaching is a secondary practice for the newcomers.

Table 7. Continued

Guided by construction of identity	**UTPD should enact strategies and activities that leads to construction of identity.**		
	(a) Teacher identity as a determining factor in teacher motivation, satisfaction, and commitment to work (Day, Kington, Stobart, & Sammons, 2006), also contributes to teacher retention and lack thereof leads to teacher stress and burnout (Izadinia, 2015a).	(a) Reflective practice enabled teachers to shape and reshape identity. Reflection is a tool to critically analyze the self and negotiate experiences to construct identity (3.8.2).	Use reflection journaling as a tool to prompt reflection on their identity construction (For example, I prompted the teachers to reflect on their role as an engineering teacher, as a CoP member, and as a teacher during all the three meso-cycles)
	(b) Identity, then, as an ongoing and dynamic process which entails the making sense and (re)interpretation of one's own values and experiences (Flores & Day, 2006).	(b) Mentoring practice validates engineering teacher identity by demonstrating competence, and positive coping behaviors strengthen identity formation (5.6.2, 5.6.4).	Support the teachers during mentoring newcomers through critical discussions in the safe space Develop insights on representation of marginalized populations in engineering in the context of operation (such as gender, race, sexual orientation, socio-economic status) Ensure academic achievement (such as certification, transfer credits) as a result of UTPD, and recognition of such achievement to wider audience like the community and family of teachers

Table 7. Continued

Guided by systematic iterations	UTPD should integrate systematic iterations to the design and implementation of the PD.		
	Uncertainties due to the nature of fragile contexts, and lack of evidence-based models for untrained teacher development in engineering requires design solutions to have systematic iterations to continuously analyze, explore, design, and improve (McKenney & Reeves, 2012).	Iterative nature of the teacher professional development resulted in flexible timeline to accommodate uncertainties and supports model for continuous improvement of the practice. (3.9, 4.10, 5.7).	(a) Inform the teachers of the longer-term duration to learn and positively affect changes in their practice (b) Ensure the teachers have understanding on the need to be iterative (for example, we used the engineering design process, a concept the teachers appreciated, to discuss similarities of that in the teacher professional development to clarify the need for iterative design)

5.1.2 Procedural design principles

As mentioned in the introduction of this section, the next table describes the procedural guidelines. They prescribe certain procedures that have been found desirable based on the evidence in this study, building from recommendations in literature through the DBR I conducted. The procedural guidelines prescribe that untrained teacher professional development should involve: (a) engaging teachers from the beginning as equal stakeholders; (b) establishing community as a safe space by building trust, empathy, open conversations, common themes, and aligning goals and expectations; (c) promoting reflection at all stages and support inquiry-based teaching; (d) using templates for research and reflection; (e) developing artifacts to serve multiple purposes, and (f) making learning whole for newcomers by providing a full experience in short timeline. Like in the table on the characteristic guidelines, theoretical and empirical supports that lead to procedural design guidelines are also presented. Before the table, I discuss the evolution process of two selected procedural design principles, with remaining descriptions for other principles expected to be in an upcoming manuscript.

Principle (a): Engage teachers from the beginning as equal stakeholders

Starting stage:

During the design of LED program for Tumaini, the students were considered as equal stakeholders in the process and were consulted during the design, implementation, and iterations through face-to-face and virtual discussions. As discussed in section 1.7, it was not until 2017 that the role of teachers became the center of planning, training, and operations of the LED program. Therefore, until 2017, we prioritized the students and considered teachers to play the role of facilitators by taking our content on the online learning platform and conveying it the students or watching as they learn. However, we faced challenges that made us re-center the role of teachers. Several literature sources and critiques on international development models in engineering guided us in shifting the role of teachers as equal stakeholders in the design and implementation of the LED and the TPD program. In their book "Engineering and Sustainable Community Development, Lucena, Schneider, and Leydens (2010) presented a case study from an anthropologist's study in Mali about a North American engineer, Pierre, who built a new kind of mill for grinding grain.

The case study discussed the bad practices followed by the engineer, such as failure to engage the local "community" while designing the mill, almost non-existent assessment including the social context and cultural impact, ignoring the assets of the local context and viewing the community only from a "problems" mindset, failure to integrate local knowledge and empower local communities on the solution making it non-sustainable. The assets-based framework discussed in section 1.5 by Ebersöhn and Eloff (2006) also presents community-based participation whereby the power is decentralized amongst the outsiders and community members as the first trend.

From these literature recommendations and aligning with the philosophy of Tumaini to be participatory, we engaged with the teachers as equal stakeholders in the design of the TPD program. However, the teachers' role as equal stakeholders evolved during different stages of our study. At the beginning, the teachers played an equal role in drafting the goals, expectations, central theme, and the logistics for the TPD. But, they preferred to be told the actions they had to take and tasks they had to perform during meso-cycle 1. For example, during the kick-off workshop (retrieved from the recordings of the workshop video), the teachers informed me that I should be the leader for the group. I engaged in a discussion noting that all of us can be leaders, and it was important for each one of us to guide the group equally, however, the teachers preferred at the beginning to have a designated authority as a leader in order for them to be accountable. Therefore, I took the leadership and facilitated the meso-cycle 1, in which I organized the meetings, assigned tasks, provided prompts for the journals, and followed-up when there were delays in submissions.

Interim stage:

During the meso-cycle 2, the teachers took an active role in the design of the intervention as the intervention, and action research itself provided more control to the teachers. During one of the CoP meetings, a suggestion made by the researcher for the teachers to become trainers of each other within the engineering CoP was well-received and together we brainstormed topics that each teacher considered as their strengths and offered training sessions to the others in the CoP. Through these discussions and training, the teachers were able to bring in cultural and contextual knowledge that became key to the LED and the TPD program. Therefore, at the interim stage, engaging teachers as equal stakeholders had evolved from developing goals and objectives together to training each other.

Final stage:

During meso-cycle 3, the teachers took charge as leaders to design the intervention of mentorship and also lead the LED program by mentoring the new teachers. As presented in section 4.6.1, the teachers considered the engineering CoP a space for each other to contribute in the design, implementation and the iteration of the activities. In the final stage the old teachers, similarly, engaged new teachers as trainers to train each other. For example, a training schedule created and implemented during the first term of third meso-cycle is provided below in table 8.

Table 8. Training schedule within the CoP developed by the teachers and the researcher

Date	Lead	Topic
Week 1	Dhinesh	Establishing CoP
Week 2	Dhinesh	ABCD Engineering Framework
Week 3	Dhinesh	Engineering classes content
Week 4	Ellie	Communication
Week 5	Carrie	Teamwork
Week 6	Sandra	Class preparation
Week 7	Frankie & William	Teaching methods and techniques
Week 8	Sandra & Dhinesh	Facilitation vs Instruction

The table above also signifies the effort of bringing the new teachers and considering them as equal stakeholders to design and conduct training sessions, overcoming the power differences between the teachers (refer section 4.6.1). Therefore, in the final stage the teachers were engaged as equal stakeholders by designing training and integrating newcomers as the teacher professional development experts themselves.

Principle (b): Establish community as a safe space – build trust, empathy, open conversations, and aligning goals and expectations

Starting stage:

The procedural design principle of establishing community as a safe space evolved through various forms and iterations during the DBR study. On 2nd February 2018, during the kick-off workshop, the teachers and I drafted the goals and expectations for us to form the collaborative community. Amongst those, some of the expectations were related to ensuring meaningful collaboration. They included:

- Have respectful and honest communication with each other
- Be impartial to each other
- Identify each other as a resource to support the practice
- Accept corrections and feedback in a positive way

These expectations initially drafted served as guidelines during meso-cycle 1 to ensure a sense of belonging in the community. Literature provided additional evidence on the importance of collaboration among teachers by building trust, and empathy. Grounded in the assumption that teacher growth does not happen in isolation based on the situated learning framework, recent professional development models seek to create learning communities where participants engage in meaningful activities collaborating with peers to co-construct knowledge about teaching and learning (Darling-Hammond & Bransford, 2007; Shulman & Shulman, 2009). Several scholars advocated for building social capital and cognitive factors such as connectedness, trust, empathy, and reciprocity among social members (Fischer, 2011; Musanti & Pence, 2010; Preece, 2004) to foster collaboration and cultures of participation in teacher professional development.

Interim stage:

At the end of meso-cycle 1, the evaluation results demonstrated the collaboration the teachers were able to create as means of mutual engagement and identity development. For example, Sandra demonstrated empathy towards Ellie's challenging situation with mathematical calculations. However, as noted in section 2.9.1, the teachers faced challenges during collaboration such as resistance to teach in front of other teachers. Therefore, at this stage, discussions around critical friendships began where in the community to foster trust and comfort. Through the notion of critical friendship (Blake & Gibson, 2020; Ponte, 2002), we developed a three-point rule for further engagement. The three-point rule was:

(1) Ask ‘wh’ questions to prompt critical thinking

(2) Make no judgement

(3) Take criticism positively as vehicle for growth

Evaluation from meso-cycle 2 revealed that the teachers developed a sense of vulnerability (refer section 3.9.1) that as a result led to open conversations about challenges faced by each other. Teachers identified each other as resource persons who could provide directions to complex and challenging questions. The weekly collaboration meetings transformed into critical friends’ meetings, where the time and space were used to being critical. As discussed in section 3.9.1 and 3.9.3, developing critical friendship took time and effort to resolve cultural and contextual limitations and realize the full benefit leading to trust, and open conversations. Additionally, having common themes, and aligning the goals and efforts of the individuals and the organization extended the community to have open and critical conversations. Therefore, by the end of meso-cycle 2, the community transformed from merely collaborating in performing the tasks of engineering teaching to a critical friendship and a platform for collective growth.

Final stage:

During the meso-cycle 3, as the benefits of the engineering CoP were communicated to the newcomers and the rest of Tumaini community by the oldtimers, there was interest from others to join the community. A significant change was the interest communicated by the director to be part of the CoP. During a critical friend meeting amongst the teachers, I conveyed the message that the director was interested to be part of our engineering CoP and develop his teaching skills and asked for the members’ thoughts. The teachers first showed reluctance. Meeting recording from 16th May 2019 showed the discussion that happened at the meeting.

> “Ellie – I am not sure. We have a good relationship there. I like him, he is a good friend and mentor. But I feel we will not be comfortable. Also, we have gone through so much. He can’t just come and join now without doing all the work we had to do to form this.
>
> Sandra – I agree. But it might actually be good for us. I might be the only one to say this but with him in the CoP we can be open about our efforts and challenges. We can show all our good work.
>
> Carrie – I don’t have a problem. I agree with Ellie that it might be uncomfortable but if we can overcome that, then like Sandra says we might be okay

> Ellie – Yeah. Okay maybe we can do one thing. We have to talk to him first about our CoP. Like all the guidelines like we did together first. And also, we want to know why he wants to be part of the CoP.
>
> Dhinesh – Like a motivation statement? Maybe we can invite him to the next meeting and say that he needs to convey his motivation and how he will engage.
>
> Sandra – Yeah that will be good. And also, we can say like, you can't come in as a director but only as a critical friend."

Finally, the director was invited to give a motivation statement speech and how he will not use the CoP meetings as a place to make judgements about his employees. The director was then admitted in the CoP and continued through the rest of the year performing the tasks as any other member of the community. As presented in section 4.6.1, evaluations from meso-cycle 3 revealed that the teachers found the CoP a safe space to communicate with other members of the organizations including those at the top end of the hierarchy without reservations. The community as a safe space evolved as a key need as demonstrated by the teachers throughout the program that led to accomplishing the goals of the LED program and the TPD program with confidence and comfort.

Table 9. Procedural design principles for Untrained Teacher Professional Development (UTPD) for Engineering Teaching in Fragile Contexts

Procedures	Theoretical/Literature Support	Empirical Support	Design Guidelines
Engage teachers from the beginning as equal stakeholders	Close collaboration between researchers and participants from the beginning is necessary to situate the needs of the community, identify problems, and design contextually relevant solutions (Barab & Squire, 2004; DeBoer et al., in review; Herrington et al., 2007).	Close collaboration resulted in creating contextually relevant course materials (2.2.3), establish the sense of community pursuing shared goals (2.3, 4.9.1), and overcame power differences (2.9, 5.6.1).	Use technological options such as WhatsApp, Zoom, and also face-to-face interactions to communicate often. Have teachers involved at every stage such problem analysis, brainstorming etc. Do not involve teachers only to get feedback on ideas but involve them to co-generate ideas.

Table 9. Continued

Establish community as a safe space - build trust, empathy, open conversations, common themes, and aligning goals and expectations	Teachers collaborating in pursuit of an enterprise should engage in critical dialogues, support each other without judgements, align individual and institutional goals with that of the central theme of the group (Altrichter et al., 2007; Wenger, 1998).	Critical friendship meetings became a safe space for individuals to engage in critical dialogues (4.9.3), and increasing opportunities to collaborate (e.g., peer observation, mentor pairing, co-teaching) further improved interpersonal relationships (3.8.1, 4.9.1, 5.6.1, 5.6.3).	Establish protocols for critical friends' meetings, and guidelines for critical friendships considering the organizational and personal relationships existing amongst the teachers. Conduct demo sessions of peer observations, and co-teaching using micro-teaching method. As a researcher or educational designer, be available for face-to-face interactions regularly during the critical friends' meetings, or demo sessions and participate as just another teacher. (for example, I taught classes and let teachers observe and give feedback, I did trainings during CFM as all the teachers did, and I also participated in journaling)

Table 9. Continued

Promote reflection at all stages and support inquiry-based teaching plan, act, observe, reflect cycle	Reflection is a powerful tool for learning (Larrivee, 2000); The plan, act, observe, reflect cycle of action research empowers teachers with a framework to improve teaching outcomes (Noffke & Stevenson, 1995).	(a) Strategies used to promote reflection (Journals, CFM, peer observation feedback) became a tool for learning throughout UTPD (3.6, 4.9.3). (b) Plan, act, observe, reflect became the framework for improving practice iteratively (4.9.4, 4.10).	Support reflective activities by reviewing journals and prompting questions during CFM or additional journal exercises. Support every step of action research by giving feedback frequently on the status and share resources such as tutorials, articles, books.
Templates and examples for reflection, research	Teachers must have tools to learn from practice by analyzing what and whom they are teaching, what is succeeding from minute to minute and day to day and how to engage and sustain student learning (Darling-Hammond, 2006).	Templates helped structure journaling and prompting deep reflection (3.6) and learn the steps of research (4.8).	Identify tested templates for lesson planning, daily reflections, prompted reflections, action research stages, and other key activities Adopt the templates in your own practice to demonstrate relevance and applicability. Share the template and how it has been adopted to provide reference.

Table 9. Continued

Artifacts to serve multiple purposes; Both as professional development tools, and repertoire of practice	Artifacts/tools/resources should serve multiple purposes for the teachers to support their professional development training, while also becoming a reified artifact of their practice (Wenger, 1998).	Tools recommended and integrated during the strategies of reflective practice, action research, and mentorship supported improvement of practice and became a common language that insiders of CoP demonstrate unique knowledge of the enterprise, and use in the institution (5.6.1, 5.7).	Encourage discussions and ways of using repertoire developed from TPD to other practices. Continue to integrate the terms of tools into the institutional language (for example, terms like journaling, critical friends, engineering design process, all have defined meanings for the teachers and the Tumaini staff community)
Make learning whole – Play the whole game for newcomers	In a short time, in some version, engage the participants to experience the whole experience of being part of the PD before the teachers can make informed choices and stay motivated (Perkins, 2010).	Teachers demonstrated understanding and motivation to pursue the enterprise upon gathering a short-term experience of the tasks undertaken; such as the LED program via the short EDP workshop (2.3), reflective practice via short journaling and CFM exercises (3.6), and action research via small scale research cycles (4.6).	Design short-term workshops, retreats to provide a small version of the whole practice such as engineering teaching, reflective practice, action research, and mentoring.

5.2 Summary

My dissertation is at the conflux point of significant national-level policy changes and recommendations in the fields of education and youth development, respectively, in Kenya. The report on the National Street Families Census of 2018 was released on June 10, 2020, and it calls for action on creating comprehensive rehabilitation response strategies by service providers with education as a priority. The report also recommended that providers should create educational provisions that equip the youth with skills to become self-reliant. The second most significant change is the shift of Kenya's school education from the traditional content-based framework to "Competence-Based Curriculum (CBC)" that came into effect in 2019. The CBC shifts the Kenyan schools to a learner-centered approach to equip learners with seven keys 21st-century competencies/skills and freedom of choice for the learners to choose different pathways at the senior level. Amongst the pathways, the reform has emphasized the significance of STEM education and creating specialized STEM high schools to address the need for a more skilled workforce in the fields of science, technology, engineering, and innovation. The curriculum shift comes with the recommendation for teachers to be trained using formal and informal ways, on pedagogical content knowledge, reflective practice, advanced teaching methods and tools, ICT integration, mentoring, and with a long-term goal of constructing positive teacher identity. With the fully established Localized Engineering in Displacement (LED) program and the Untrained Teacher Professional Development (UTPD) program, Tumaini can be at the forefront of these significant developments in the country. This dissertation research adds value to the UTPD program by discussing the design, development, and evaluations of an informal teacher training program. The study further adds significance to the generated design principles. I summarize below the four chapters presented above to outline the purpose of this research, and the three studies that informed the developments.

5.2.1 Chapter 1

Motivated by the relevance of the engineering for former SY at Tumaini Innovation Center, we designed an authentic, problem-solving, Localized Engineering in Displacement program that builds on the SY's inherent resourcefulness of resilience, social cohesion, and self-esteem (Radhakrishnan & DeBoer, 2016). Our prior research in the program demonstrated the role of

teachers as agents of change (Radhakrishnan & DeBoer, 2018). However, the teachers participating in the program lacked knowledge, skills, and attitudes about engineering teaching, which was intensified by their lack of formal teacher education or training. The three teachers themselves were equipped with the assets of intrinsic motivation, cultural and contextual knowledge, and experience working with the SY population. In order to enable them to be engineering teachers, collaboratively with the three teachers, I designed and studied a capacity building program. Design-based research, as the research methodology, was found to be uniquely suitable for the problem statement that was central to this study. As discussed extensively in Chapter 1, the exercise of designing professional development interventions for untrained teachers was complicated by several factors, such as lack of literature, contextual constraints, and cultural barriers. The attributes of design-based research rendered this approach compatible with the needs of the situation, due to its iterative nature and the ability to simultaneously pursue the goals of designing effective learning environments (in this case, professional development on engineering teaching for untrained teachers), and use of such environments as natural research sites to study (untrained) teacher development (Sandoval, 2004). The four micro-cycles of analysis, design, evaluation, and reflection of DBR provided the procedural guideline in the study. Situated learning theory and a Communities of Practice framework further provided the theoretical structure for the study by informing the learning of the teachers via participation in the professional development program as a unit of analysis. The CoP framework components served as structural guidelines during the design and evaluation of the design solutions. By using both the theoretical and methodological framework, we designed three interventions (built on each other sequentially) to improve the untrained teachers' practice of engineering teaching.

5.2.2 Chapter 2

The analysis micro-cycle of DBR's first meso-cycle in this research helped us identify that the teachers were motivated to facilitate the engineering program given the interest demonstrated by the students but lacked understanding of the practice of engineering teaching and on their role as engineering teachers. In the design micro-cycle, the reflective practice was identified as a learning strategy to address the identified problem. Therefore, we engaged in various critical reflection activities for three months, as a result of which the teachers developed a sense of collaboration amongst themselves and became self-reliant as well as resilient to the ever-changing

demands of the fragile community. We collected data from weekly meetings among critical friends, teacher journals, conversations in a messaging app, and supporting documents. We used thematic analysis in the evaluation micro-cycle to interpret the findings. We identified that the teachers were increasingly becoming aware of their capacity to reflect-in-action and reflect-on-action, and as a result of the collaboration initiated, an organic community of practice evolved. The evaluation cycle also demonstrated that the teachers continued to face challenges in classroom practices, using appropriate teaching methods for engineering content, and strengthening the collaboration that had been formed to support each other in their development.

5.2.3 Chapter 3

In this chapter, I discussed the second meso-cycle, which was informed by the first meso-cycle. In order to address the gaps identified during the evaluation of reflective practice, we conducted a literature review to identify best practices in teacher professional development to improve teaching practice. We determined that action research has the potential to develop self-understanding of the practice, the discipline, and the "own-selves," through systematically improving teaching (Goodnough, 2010), which was critical to sustaining meaningful development efforts. Therefore, in this second meso-cycle, the teachers used action research to improve teaching engineering, building a stronger community of peer teachers, and learning to do research. Analysis of the data suggested that the untrained teachers, by adopting action research, strengthened their practice by developing their pedagogical content knowledge, providing meaningful learning to students, becoming vulnerable amongst critical friends, and transferring knowledge of engineering and research to other practices.

5.2.4 Chapter 4

As described in the previous two sections, undertaking reflective practice and action research improved the teachers' engineering teaching knowledge, skills, and attitudes; in particular, these activities provided tools and pathways to resolve challenges using the competencies in the community. However, the primary educational problem of untrained teachers' continuous professional development in fragile contexts was not wholly addressed, yet. The teachers discussed during the evaluation of meso-cycle 2 that unresolved challenges impeded their ability to

demonstrate their identity as engineering teachers to members outside the CoP and to ensure the future of the teacher professional development program. The literature on TPD called for action from scholars and practitioners to create teacher professional development that is continuous and long-term. Therefore, the established CoP had to be sustainable and serve as the structural framework for continuous development to occur. The sustainability and continuous development of knowledge and practice in a CoP happen through expanding the CoP over time. Expansion of a CoP means welcoming new members in the community who can be guided by mature practitioners through the process of 'legitimate peripheral participation.' Therefore, we identified mentorship as the third meso-cycle that improves the outcomes of reflective practice and action research activities undertaken by the teachers.

In this third study, we investigated the role played by the experienced teachers in the engineering community of practice to mentor the incoming teachers and how it strengthened the knowledge, skills, and attitudes of the mature teachers. Results indicated that mentorship enables matured practitioners to induct newcomers and develop a shared understanding of the practice. We also found that mature teachers constructed positive identities as an engineering teacher. The study has demonstrated mentorship as part of a robust step towards a long-term, self-sustaining model for untrained teacher professional development in engineering.

5.2.5 Chapter 5

Finally, as a result of the efforts in this design-based research study, I presented the design principles generated. Design principles are not intended as recipes for successful designs. Instead, "*they are theory-based conjectures, which underpin the design, and are refuted, validated or refined based on the research findings*" (Herrington et al., 2007). The design guidelines generated include guidelines on characteristics to ensure a successful outcome for untrained teacher professional development in fragile contexts and guidelines on procedures that can be adopted while designing or implementing the program.

The characteristic design guidelines (Table 5) prescribe eight main characteristics of professional development based on this study. According to the table, this study typifies professional development as guided by: (a) the philosophy of learning as participation in a Community of Practice, (b) the critical reflection of the self and the activities performed, (c) collaboration and a learning community, (d) needs of students, institution, and the teachers, (e)

opportunities to link practices and transfer knowledge, (f) continuous professional development and sustainability, (g) the construction of identity, (h) systematic iterations. For each of these themes, the table presented relevant theoretical and empirical evidence that lead to more specific characteristic design guidelines.

Table 6 described the procedural guidelines. They prescribe specific procedures that have been found to be desirable based on the evidence in this study and are also aligned with recommendations in the literature. The procedural guidelines specify that professional development should: (a) engage teachers from the beginning as equal stakeholders, (b) establish community as a safe space - build trust, empathy, open conversations, common themes, and aligning goals and expectations, (c) promote reflection at all stages and support inquiry-based teaching plan, act, observe, reflect cycle, (d) utilize templates and examples for reflection, research, (e) allow artifacts to serve multiple purposes; comprise both as professional development tools and repertoire of practice, (f) engage teachers in short versions of the full TPD experience at the start. Like in the table on the characteristic guidelines, theoretical and empirical supports that lead to procedural design guidelines are also presented.

5.3 Conclusion and Future Work

This study's significant contribution to practice has been in the design and implementation of a professional development program that is viable and effective for strengthening the work and the development of untrained teachers and thereby the informal spaces in which they work. From a scientific perspective, this study provides a detailed description and reflective critique of a feasible and effective professional development program, as well as design guidelines and a model that offer insights into how similar work could be undertaken in comparable settings. This contribution is valuable because untrained teachers' professional development has received little attention in practice, research, or theory development, although such programs are extensively implemented or demanded in educational efforts in developing countries. As a first step, this study builds exposure for the critical role untrained teachers can play in facilitating programs like engineering that are in high demand and relevant for national interests in developing countries. The research findings from KNUT concluded that if teacher's development is not given the attention it deserves, the well-intended CBC implementation will cause decline in educational standards in Kenya. Therefore, scholars in the country, and the teacher associations agree that collective efforts are

needed to prepare the teachers and learners to competencies that contribute to the national agenda (The Elephant, 2019). This dissertation provides a model for informal teacher development to address the urgent need for improving both trained and untrained teacher capacity across the country.

Further research and development activities are warranted to serve better the widely employed, much-needed workforce of untrained teachers in developing countries. This research would include a number of important aspects. First, a long-term project that aims to contribute to and profiles the developmental stages that untrained teachers go through in building their engineering self-efficacy would have tremendous value for informing improvements in learning quality in fragile contexts. Two, experiences during this study suggested the need to research long-term impacts on the teachers, the students, and the established community of practice. Three, the uniqueness of the context in this study prompts a separate investigation into the cultural and contextual drivers and barriers, for example including a deeper query of gender roles, for untrained teacher professional development in engineering.

In my continuing role as a facilitator, co-designer, co-researcher, leader, critical friend, CoP member, and "Kariuki" at Tumaini, I aim to continue participating in the activities of the LED and TPD program during the next year. As immediate next steps, I will continue to support the mentorship program and extend the results of the third meso-cycle to include the full-term evaluation. We will also assess the teachers on their action research and mentoring projects and certify them. In addition, I will continue the research efforts on this TPD as a longitudinal study and identify ways of translating it to other fragile contexts.

For the director, the teachers, the DeBoer Lab, and myself, the question that the student raised at Monday assembly, asking why the students should not demand BETTER opportunities than a bare minimum of provisions, motivated this dissertation. It inspired five years of rigorous, challenging, sometimes overwhelming work. It motivated the three papers of this dissertation and the multiple other grant applications, conference and journal articles, study abroad programs, local university collaborations, guest lectures, and visiting scholar exchanges. And still, the question remains. I cannot help but see even more work to be done. In focusing this dissertation on the teachers and on catalyzing their assets in a novel, sustainable, state-of-the-art pedagogical endeavor, I have tried to center this question and ensure that it continues to echo in the community of educators serving Tumaini youth. To the director's question, "are we doing everything we can

for the youth to be better individuals", this dissertation is not the end, but one of the many beginnings.

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APPENDIX A: KENYA STREET FAMILIES CENSUS RESULTS FROM 2018

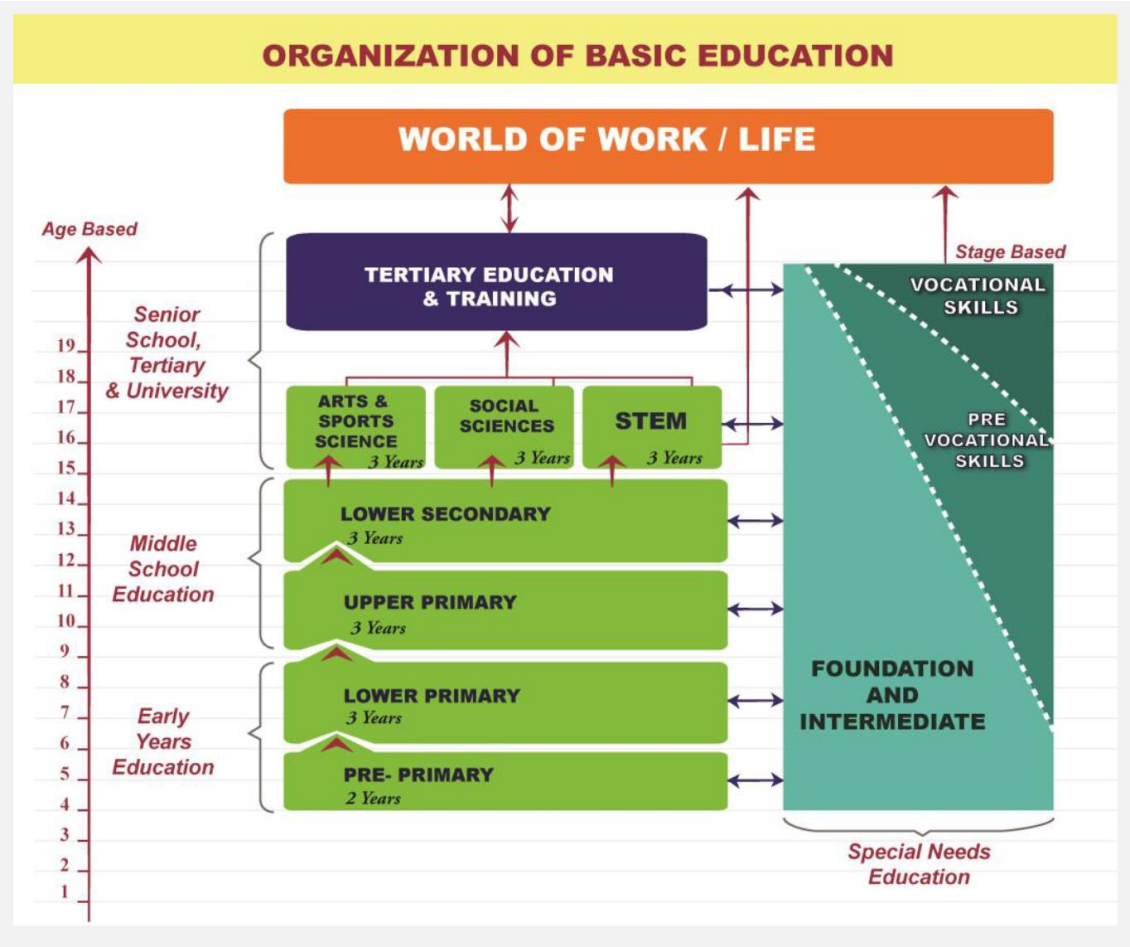
(Street Families Rehabilitation Trust Fund, 2020, p. XV)

Street Families Census Results at a Glance

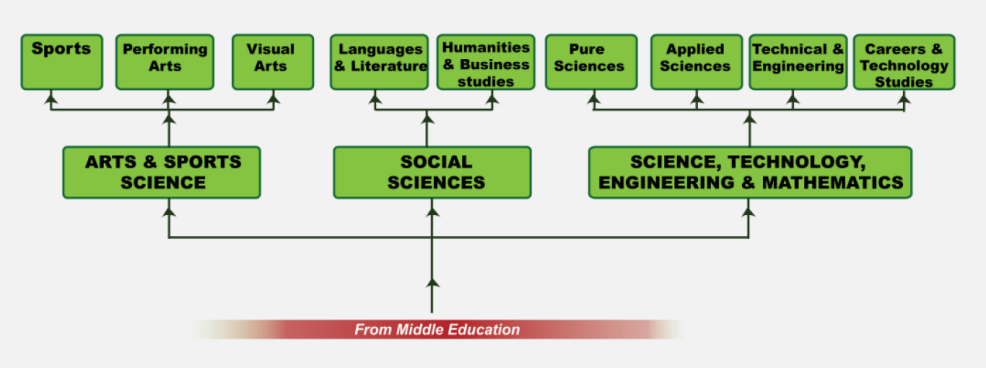
Indicator	Male	Female	Total (N)
Proportion of Street Persons in the Streets of the Country	72.4	27.6	46,639
Proportion of Street Persons under Rehabilitation in Institutations			7,206
Proportion of Street Persons by Level of Education			
No Education	60.9	39.1	7,786
Pre-primary/Primary	74.2	25.6	31,976
Post primary and Above	76.8	23.7	6,877
Proportion of Street Persons by Marital Status			
Never Married	69.0	31.0	3,630
Married/Living Together	68.2	31.8	9,592
seperated/ Divorced	52.8	47.2	6,300
Proportion of Street Persons by Talents			
No talent	65.6	34.4	24,662
Have some talent (Ball games, Singing, Art/Craft, etc.)	80.0	20.0	21,977
Proportion of Street Persons With Vocational Skills			
No skills	72.4	27.6	33,073
Have some skills (carpentry & joinery, masonry, welding etc.)	72.5	27.5	13,566
Proportion of Street Persons Living with Parents in the Streets			
Proportion not living with parents	69.8	30.2	36,057
Proportion living with parents	81.1	18.9	10,582
Proportion of Street Persons Living with Parents in the Streets			
Death of one or two Parents	75.3	24.7	5,868
Mistreatment	72.9	27.1	4,416
Other	70.7	29.3	39,744

APPENDIX B. NEW BASIC EDUCATION STRUCTURE – 2-6-6-3 EDUCATION FRAMEWORK

(Kenyan Institute of Curriculum Development, 2017, p. 28)

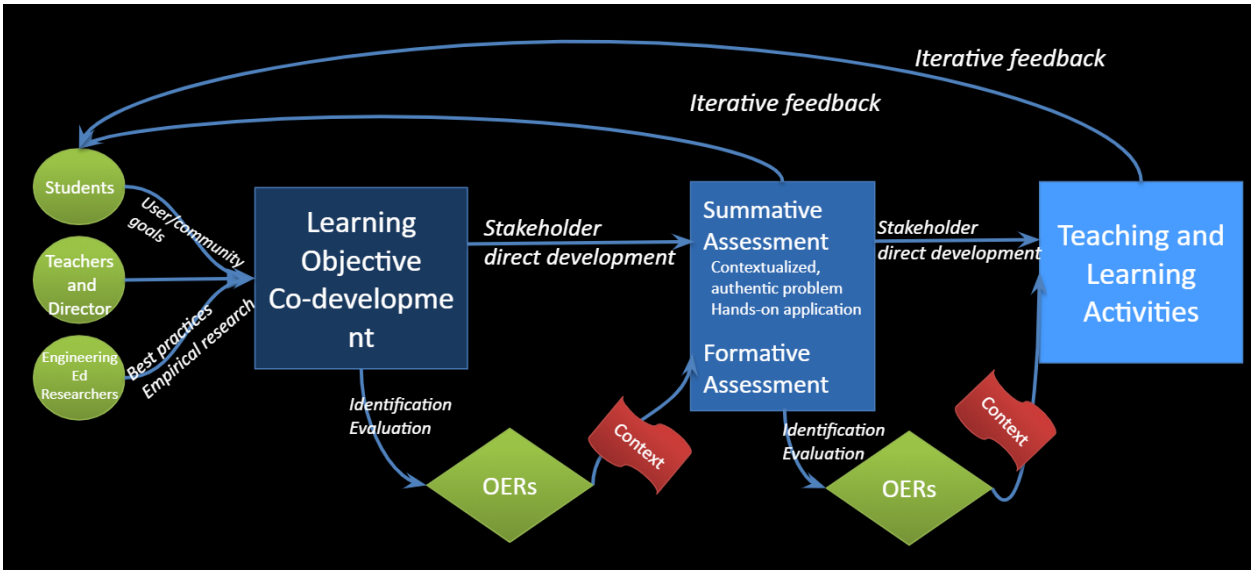


Tracks within Senior School Pathways (p. 54)

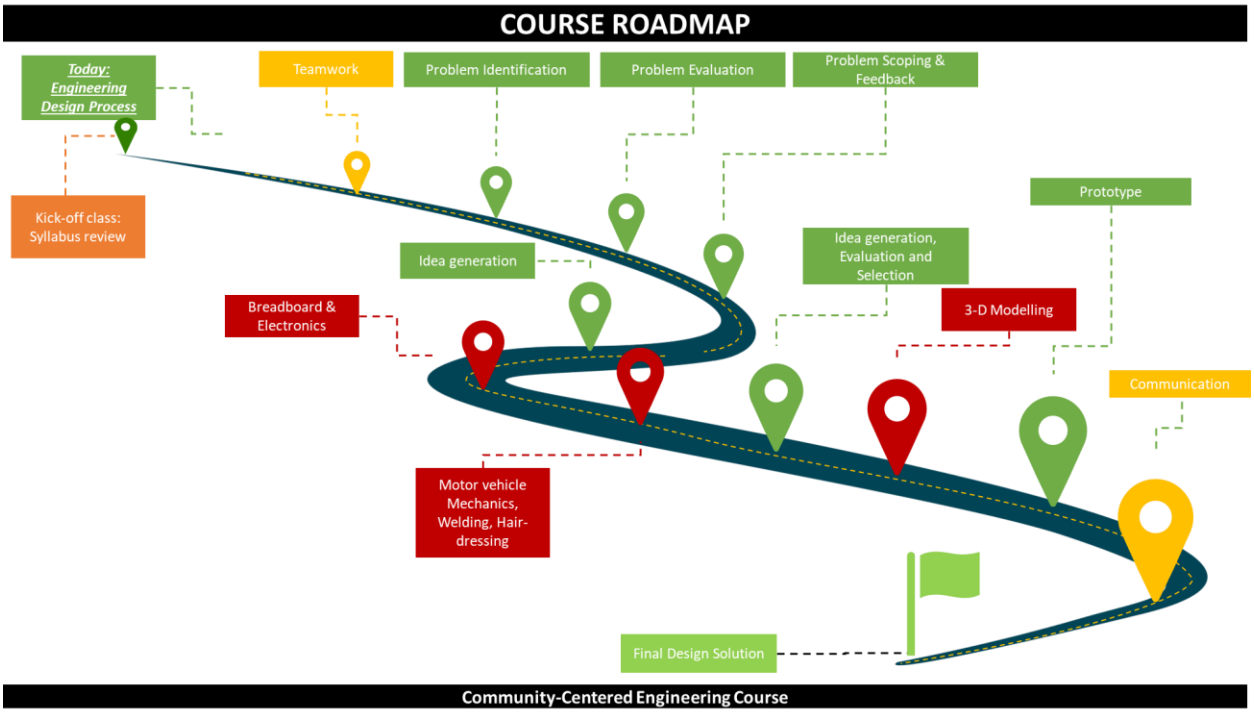


APPENDIX C. LED CURRICULUM

Curriculum Co-Development Process at Tumaini



Version 2 LED Course Roadmap Implemented during 2019



APPENDIX D. CONSENT FORM

RESEARCH PARTICIPANT CONSENT FORM

Engineering skill curriculum and digital materials for out-of-school youth

Dr. Jennifer DeBoer
School of Engineering Education
Purdue University

Key Information

Please take time to review this information carefully. This is a research study. Your participation in this study is voluntary which means that you may choose not to participate at any time without penalty or loss of benefits to which you are otherwise entitled. You may ask questions to the researchers about the study whenever you would like. If you decide to take part in the study, you will be asked to sign this form, be sure you understand what you will do and any possible risks or benefits.

Project Rationale

We are doing a research study. A research study is a special way to find out about something. We want to find out how we can involve young students to learn engineering skills using digital tools. We have developed an approach to unlocking young students' capacity to engineer through our on-going program at Tumaini. Our curriculum uses problems to find solutions using engineering design process. Our project also involves development of teacher capacity in order to fully support and sustain the unique educational opportunity for students at Tumaini. The class centers around a local challenge. In order to understand the good, bad, and the difficult of this curriculum in the view of teacher participants we conduct this research study. The research project that runs alongside the engineering program and will take place for three years to study the long-term effect of the engineering with the youth and the role of teachers in it.

What is the purpose of this study?

You are invited to participate in this research study of an engineering skills curriculum and digital materials for out-of-school youth. We hope to learn your experiences with the content developed for the curriculum, using the digital platform and your interaction with the students. You are selected to participate in this study to directly support you in benefitting from the professional development of an engineering curriculum that could help in delivering employable skills to the marginalized youth. We would like to enroll all the participating students in the engineering course, and the teachers who are part of the engineering instructional team.

What will I do if I choose to be in this study?

There will be continuing sessions throughout the academic year of the course content through classroom sessions. This will be class room instruction session with the investigator, key personnel's, teachers (you) at Tumaini delivering the content to the students in the class. Some of the class sessions will be video recorded for re-visiting and analyzing the experiences. Followed by this, there will be a focus group or one-on-one interview with students and teachers (you). The interviewer's will be the

investigators. At the interview, you will be questioned about expectations, experiences and understanding of the course content and your experience of using the digital platform delivering the curriculum inside and outside the classroom.

How long will I be in the study?

This research study is expected to take approximately three years. However, each participant will be an active participant only during the time of your involvement in the engineering classes at Tumaini. The study will also cover approximately 35-50 hours of your time in three years for interviews, and feedback sessions. The class sessions in a week will be approximately 4-6 hours in total. But, not every week's sessions will be used for the purpose of research. The sessions that will be part of the research will be informed in advance to you.

What are the possible risks or discomforts?

There are no possible risks or discomforts by participating in this study. Your participation in this study is entirely voluntary. Your participation not to participate will not have any negative effect on your education or living at Tumaini Innovation Center. You can decide to participate now but withdraw your consent later and stop being in the study. Breach of confidentiality is a risk and the safeguards used to minimize the risk can be found in the confidentiality section.

Are there any potential benefits?

There are no direct benefits to the participants. A professional development opportunity for teachers – Teachers may benefit from the educational tools being provided to them on both teaching and engineering skills.

Are there costs to me for participation?

There are no anticipated costs to participate in this research.

This section provides more information about the study

Will information about me and my participation be kept confidential?

The project's research records may be reviewed by the study sponsor/funding agency, US DHHS Office for Human Research Protections, and by departments at Purdue University responsible for regulatory and research oversight. During the study we will be collecting your data from classes and through interviews. There is a problem that the data might get stolen or leaked. We will eliminate this problem by keeping your data without mentioning your name or any other personal details and in a password protected computer. Your pictures and videos taken during the study might be disseminated for media purposes. You will be informed about this when it occurs, and it will be done only with your acceptance. The data will be stored in the computer until the end of the research study. Upon completion, the data including your interview data, photos, videos will be deleted. This data will only be available to the investigators and key personnel signed in this study.

What are my rights if I take part in this study?
You do not have to participate in this research project. If you agree to participate, you may withdraw your participation at any time without penalty. You can withdraw from the study at any point. All you have to do is say "no" to the investigator. You will not be punished or suffer any consequences for saying "no" with the investigators or with members at Tumaini. You will not be able to withdraw your data from the study, once all data has been destroyed at the end of the study.

Who can I contact if I have questions about the study?

If you have questions, comments or concerns about this research project, you can talk to one of the researchers. Please contact

Dr. Jennifer DeBoer,
Assistant Professor,
School of Engineering Education,
Armstrong Hall, ARMS 1311,
+1-765-496-0195
deboerj@purdue.edu

To report anonymously via Purdue's Hotline see www.purdue.edu/hotline
If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu) or write to:

Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.
West Lafayette, IN 47907-2114

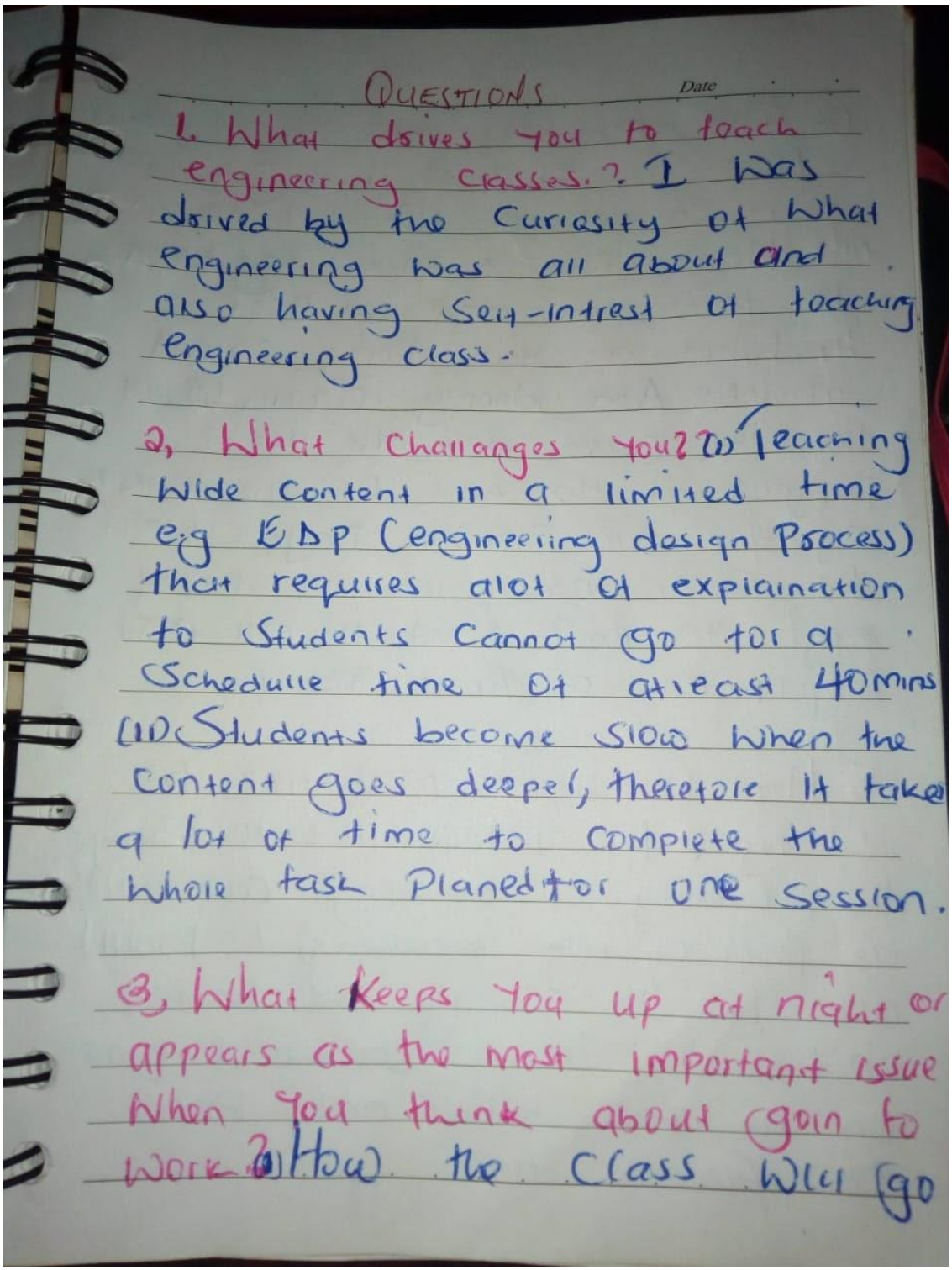
Documentation of Informed Consent
I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

_____ _____
Participant's Signature Date

_____
Participant's Name

_____ _____
Researcher's Signature Date

APPENDIX E. SAMPLE PROMPTED JOURNAL OF A TEACHER

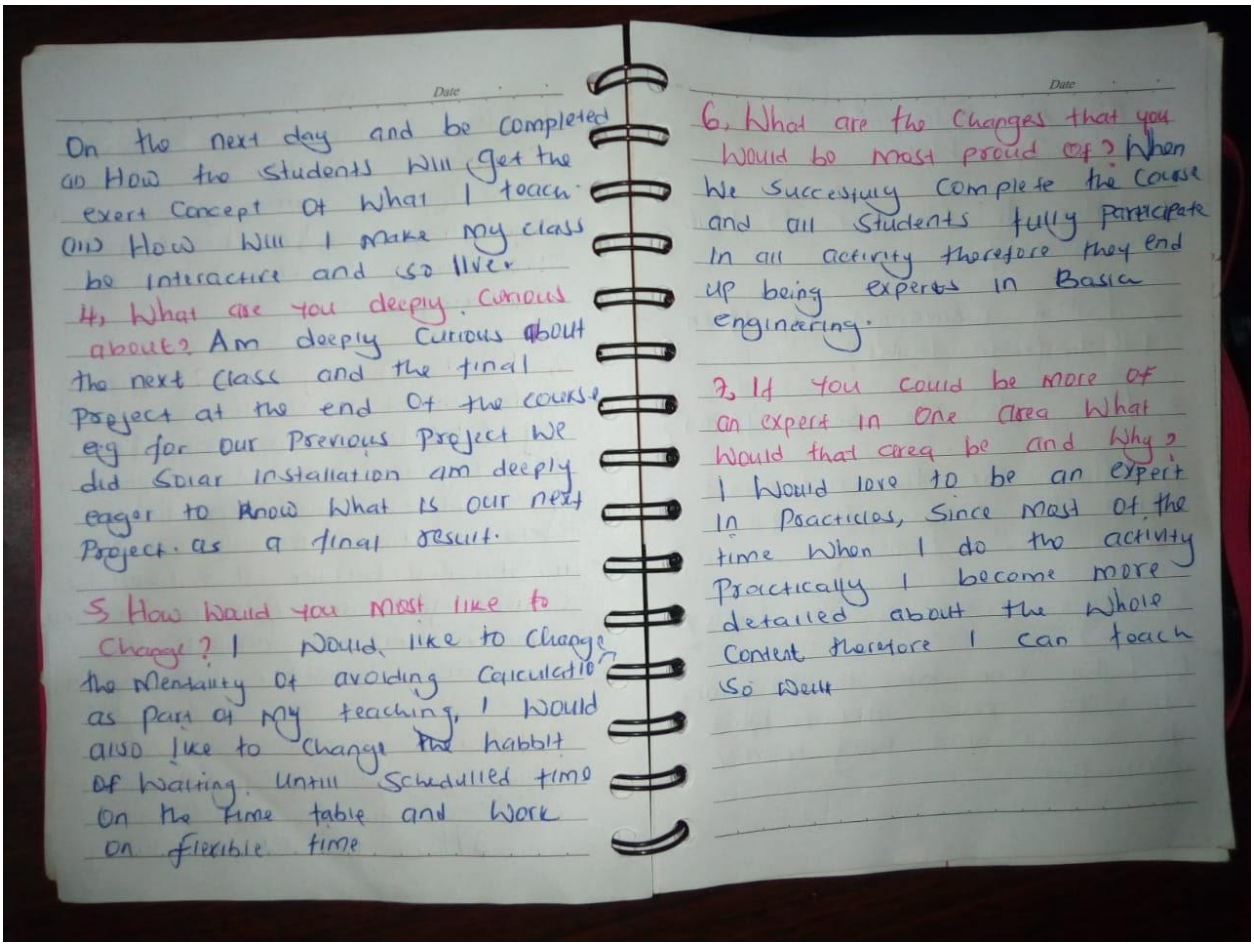


QUESTIONS Date

1. What drives you to teach engineering classes.? I was drived by the curiosity of what engineering was all about and also having self-intrest of teaching engineering class.

2, What challanges you? (i) Teaching wide content in a limited time e.g EDP (engineering design Process) that requires alot of explaination to students cannot go for a schedulle time of atleast 40mins (ii) Students become slow when the content goes deeper, therefore it takes a lot of time to complete the whole task planed for one session.

3, What keeps you up at night or appears as the most important issue when you think about going to work? (i) How the class will go



Date

On the next day and be completed
ao How the students will get the exert Concept of what I teach
OND How will I make my class be interactive and so liver

4, What are you deeply Curious about? Am deeply Curious about the next class and the final Project at the end of the course eg for our Previous Project We did Solar installation am deeply eager to know what is our next Project. as a final result.

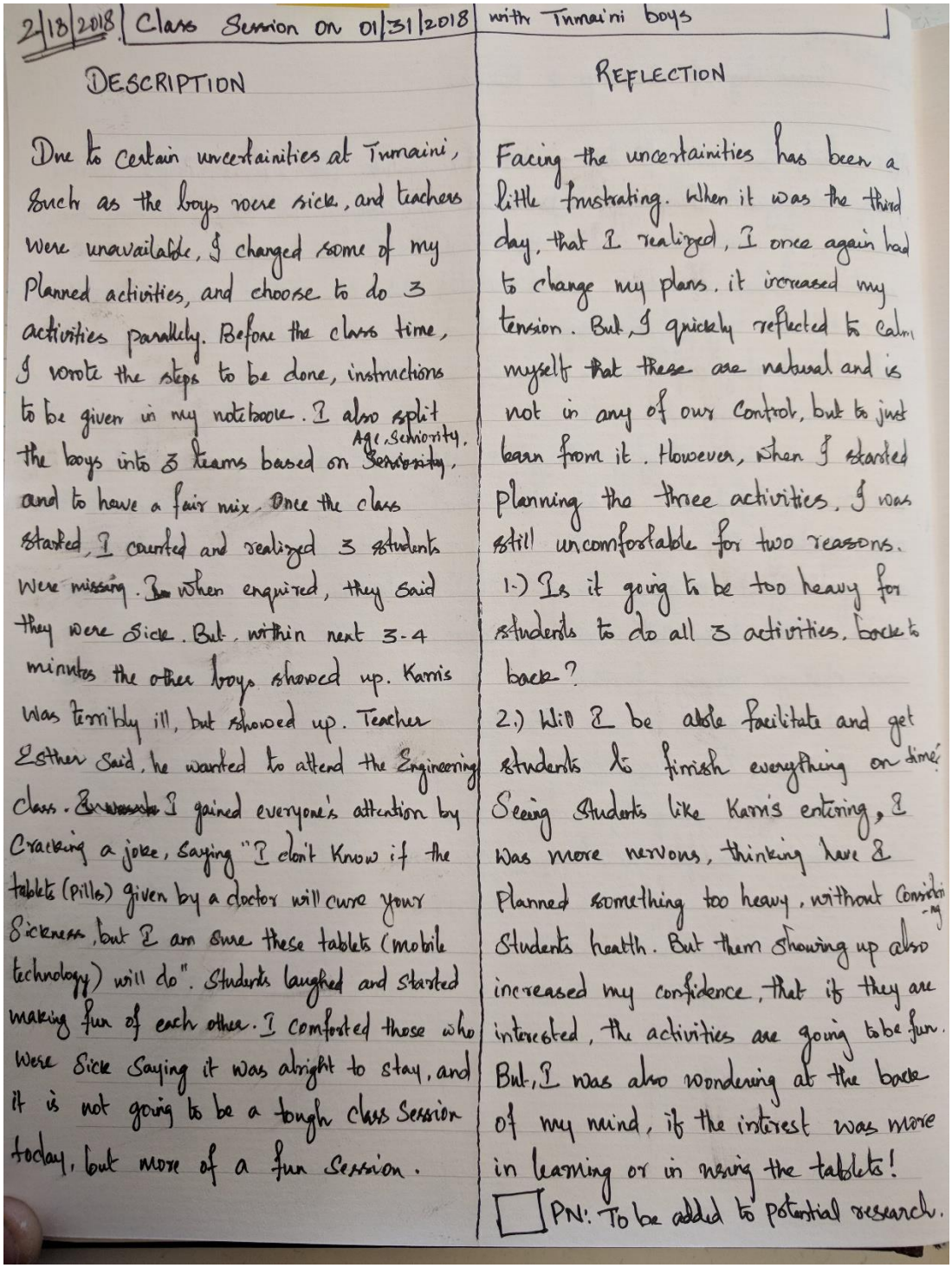
5 How would you most like to Change? I would like to Change the Mentality of avoiding Calculation as part of my teaching, I would also like to Change the habbit of waiting Until Scheduled time On the time table and work on flexible time

Date

6. What are the Changes that you would be most proud of? When We Successfully Complete the Course and all students fully participate In all activity therefore they end up being experts in Basic engineering.

7, If you could be more of an expert in One area What would that area be and Why? I would love to be an expert In Practicles, Since most of the time When I do the activity Practically I become more detailed about the Whole Content therefore I can teach So Well

APPENDIX F. SAMPLE DOUBLE ENTRY JOURNAL OF RESEARCHER USED BY THE TEACHERS AS REFERENCE



2/18/2018 | Class Session on 01/31/2018 | with Tumaini boys

DESCRIPTION

Due to certain uncertainities at Tumaini, such as the boys were sick, and teachers were unavailable, I changed some of my planned activities, and choose to do 3 activities parallely. Before the class time, I wrote the steps to be done, instructions to be given in my notebook. I also split the boys into 3 teams based on Age, Seniority, and to have a fair mix. Once the class started, I counted and realized 3 students were missing. When enquired, they said they were Sick. But, within next 3-4 minutes the other boys showed up. Karris was terribly ill, but showed up. Teacher Esther said, he wanted to attend the Engineering class. I gained everyone's attention by Cracking a joke, saying "I don't Know if the tablets (pills) given by a doctor will cure your Sickness, but I am sure these tablets (mobile technology) will do". Students laughed and started making fun of each other. I comforted those who were Sick saying it was alright to stay, and it is not going to be a tough class Session today, but more of a fun Session.

REFLECTION

Facing the uncertainities has been a little frustrating. When it was the third day, that I realized, I once again had to change my plans. it increased my tension. But, I quickly reflected to calm myself that these are natural and is not in any of our Control, but to just learn from it. However, when I started planning the three activities, I was still uncomfortable for two reasons.

1.) Is it going to be too heavy for students to do all 3 activities, back to back?

2.) Will I be able facilitate and get students to finish everything on time?

Seeing Students like Karris entering, I was more nervous, thinking how I Planned something too heavy, without Considering Students health. But them showing up also increased my confidence, that if they are interested, the activities are going to be fun. But, I was also wondering at the back of my mind, if the interest was more in learning or in using the tablets!

☐ PN: To be added to potential research.

APPENDIX G. SEMI-STRUCTURED INTERVIEW PROTOCOL

Semi-Structured Interview Protocol

Common prompts during all three meso-cycles:

- Tell me about your experience of teaching the engineering class

  Additional prompts:

  - Based on the response - What factors lead to the improvements/challenges?
  - Among all the different activities we carried out what were the ones that worked the best for you?
    - Can you rate them in the order of your most favorite to least?
      - And explain why?
  - What are the challenges that you faced in last two months?
  - How would you describe your teaching in last two months compared to before?
- Tell me what you think are the qualities needed for a good engineering teacher, and why?

Community of Practice

- Tell me about your experience of being part of this teacher community of practice
  - What are all the ways you have utilized this community? More effective and less effective?
  - What have you contributed to the learning of others in this community?

Additional prompt:

  - What do you think you (as a teacher) have learned from this community?

Specific prompts during meso-cycle 1:

Reflective practitioners:

- Tell me about your experience of using reflection strategies

Additional prompt:

- In what ways did reflection help you transform your practice?
- If you were to talk about reflection (or) reflective practice to a friend, how would you describe it?

Specific prompts during meso-cycle 2:

Action Research

- Tell me about your experience of doing action research

Additional prompt:

- In what ways did action research help you transform your practice?
- If you were to talk about action research to a friend, how would you describe it?

Specific prompts during meso-cycle 3:

Mentorship

- Tell me about your experience of mentoring new teachers

Additional prompt:

- In what ways did mentoring help you transform your practice?
- If you were to talk about mentoring to a friend, how would you describe it

VITA

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Current Appointments

Team Lead – Kenya — August 2019 – Present
Purdue Global Engineering Programs and Partnerships – AMPATH

Research Coordinator — January 2019 – Present
Connected Learning in Crisis Consortium

Research Assistant — August 2015 – Present
DeBoer Lab – Research Group in Engineering Education, Purdue University

Areas of Specialization

Engineering education, participatory research, international development, engineering for community development, teacher professional development, displaced settings, action research

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Graduate:
Doctor of Philosophy in Engineering Education, Purdue University
August 2015 – July 2020
School of Engineering Education — *Advisor: Dr. Jennifer DeBoer*
Dissertation: Enabling untrained teachers to be engineering facilitators: A design-based research study of teacher professional development in fragile contexts

Master of Technology in Energy Systems, University of Petroleum and Energy Studies
August 2012 – April 2014
College of Engineering — *Advisor: Dr. Saurabh Biswas*

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School of Engineering

Papers Presented & Published

Peer reviewed journal publications

Claussen, S. A., **Radhakrishnan, D.,** Haney, C. L., Kimani, S. N., Wairimu, E., Kimutai, W., &

DeBoer, J. (2020). An innovative model for engineering study abroad in a nontraditional context: An evaluation of student and community outcomes. *Journal on Excellence in College Teaching*, 30(4), 121-156.

Dridi, A., **Radhakrishnan, D.B.**, & DeBoer, J. (2020). Challenges of Distance Learning in Refugee Camps: When Internet Connectivity Fails, Human Connection Succeeds. *The International Review of Research in Open and Distance Learning*, 21(3).

Napoli, A., Nyaga, K., **Radhakrishnan, D.,** & DeBoer, J. (Under Publication). Welder to Engineering Supervisor: Transformation of a Former Street youth in an Engineering. *Purdue Journal of Service-Learning and International Engagement.*

DeBoer, J., **Radhakrishnan, D.B.,** Freitas, C.C.S. (forthcoming) Localized Engineering in Displacement: An Alternative Model for Out-of-School Youth and Refugee Students to Engineer their own Solutions for their own Communities. *Advances in Engineering Education.*

Radhakrishnan, D., Capobianco, B., & DeBoer, J. (Under review). Becoming reflective practitioners to build a teaching practice, a community, and an identity as engineering facilitators at an alternative school for "street youth". *Reflective Practice*.

Freitas, C. C. S., **Radhakrishnan, D.,** Zywicki, S. M., DeBoer, J. (under review). Understanding Engineering Education in Refugee Camps: A Comparative Case Study of Localized Engineering in Two Refugee Camps. *Comparative Education Review.*

Yellagoud, S.K., Sharma, M., **Radhakrishnan, D.B.,** & Suresh, K. (2013), Electric Pedicab for Future India – A study and analysis for Hilly Terrains. *Global Journal of Engineering Research and Technology*, ISSN 2249-3107, Volume 3, Number 1 (2013), pp.33-41.

Peer reviewed book chapters

Radhakrishnan, D. & DeBoer, J. (2019). Youth Engineers and Their Role. Commissioned chapter, UNESCO's second Engineering Report.

Peer reviewed conference publications

Radhakrishnan, D., Kimani, S., Wairimu, E., Kimutai, W., Kimani, S., & DeBoer, J. (2019). Engineering teachers as action researchers through a community of practice at an alternative school for "street youth" in western Kenya. Research in Engineering Education Symposium, Cape Town, South Africa, 2019.

Haney, C.L., **Radhakrishnan, D.,** Kimani, S., & DeBoer, J. (2019). Tumaini Tech Project: A case study of the development of engineering self-efficacy and understandings of engineering in former "street youth" in Kenya. Research in Engineering Education Symposium, Cape Town, South Africa, 2019.

Olayemi, M., Freitas, C., **Radhakrishnan, D.,** Dridi, M.A., & DeBoer, J. (2019). Improving course retention rates in engineering education in refugee settings: Lessons from two case studies. Research in Engineering Education Symposium, Cape Town, South Africa, 2019.

Shillingford, I. **Radhakrishnan, D.**, DeBoer, J. (2018). Optimize Learning Tool through Data Analysis. Purdue Undergraduate Research Conference, November 2018.

Radhakrishnan, D.B. DeBoer, J., & Kimani, S. (2018), Teachers as Guides: The role of teachers in the facilitation of technology-mediated learning in an alternative education setting in western Kenya. Paper presented at 2018 ASEE Zone II Regional Conference, Purdue University, West Lafayette, Indiana.

Radhakrishnan, D. Capobianco, B., & DeBoer, J. (2018), But Why: Becoming reflective

practitioners to preserve originality at an alternative school in western Kenya. Paper presented at 2018 Action Research Network of the Americas (ARNA) Annual Conference, San Diego, California.

Radhakrishnan, D.B. & DeBoer, J. (2017). Former street youth experiences from a pilot study of an Active, Blended, and Collaborative Course in Western Kenya. Paper presented at the 2017 Comparative and International Education Society Conference, March 6-9, Atlanta, GA.

Radhakrishnan, D. B., & DeBoer, J. (2016), Utilizing an Innovative Engineering Skills Curriculum and Technology to Expand Classroom Learning in Low-Resource Settings. Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana. 10.18260/p.27175

Lowe, T. A., & Evenhouse, D. A., & **Radhakrishnan, D. B.,** & Hoffmann, S. R. (2016, June), Data-Driven Course Improvements: Using Artifact Analysis to Conquer ABET Criterion 4 *Paper* presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana. 10.18260/p.26641

Kandakatla, R., & **Radhakrishnan, D. B.**, & Vedula, K. (2015, June), Enhancing Learning by Empowering Indian Students to Solve Engineering Challenges: An Effort by SPEED and IUCEE Paper presented at 2015 ASEE Annual Conference & Exposition, Seattle, Washington. 10.18260/p.23999

Redda, L., & Reichl, F., & Ferrario, A., & Kandakatla, R., & **Radhakrishnan, D. B**. (2016, June), The Global Student Forum: A model for developing student leaders in engineering education Paper presented at 2016 ASEE International Forum, New Orleans, Louisiana. https://peer.asee.org/27265

Kandakatla, R., & **Radhakrishnan, D.B.** (2014, July). Impact of action plan workshop in enhancing Indian engineering education. In 12th LACCEI Latin American and Caribbean Conference for Engineering and Technology, Guayaquil, Ecuador.

Kandakatla, R., & **Balaji, R. D.** (2014, December). Diversification in Engineering Education through Indian Student Forum. In International Conference on Interactive Collaborative Learning (ICL), Dubai, UAE.

Radhakrishnan, D. B., & Kandakatla, R. (2013, August). Innovation in Indian Engineering Educational System: Study and Analysis. In WEEF 2013 Cartagena.

Suresh, K., & **Radhakrishnan, D.B.** (2012), Electricity Generation Through Pedal Power at Engineering day symposium, University of Petroleum and Energy Studies.

Radhakrishnan, D.B., & Rasaiah, K. (2008), Advanced Power Conditioning methods for wind energy systems at 2008 FUTURA, Sathyamangalam, Tamil Nadu.

Reports (Primary Author)

MIT D-Lab Alumni-Evaluation on Participation in International Development Programs. (2018). Massachusetts Institute of Technology

Refugee learning Analysis from Global History Lab Course by Princeton University. (2018). University of Geneva – InZone.

Media articles

Radhakrishnan, D., DeBoer, J., & Kimani, S. (2020a, April). A Center of "Hope" and

Innovation. *Medium*. https://medium.com/deboer-lab/a-center-of-hope-and-innovation-245d3ea495f4

Radhakrishnan, D., DeBoer, J., & Kimani, S. (2020b, April). Does "Stay at Home!" apply to everyone? *Medium*. https://medium.com/deboer-lab/does-stay-at-home-apply-to-everyone-6a4ed2b1f85f

Industry Experience

1.) Name of the organization : MarketsandMarkets, Pune
Duration : From 03rd February, 2014 to 30th June, 2015
Designation : Research Analyst - Consulting

- Handling consult projects involving technology analysis, business analysis, primary and secondary research, market engineering, conducting primary interviews
- Training and handling a team of associates under various consulting assignments

2.) Name of the Organization : Mahindra & Mahindra Ltd, (Powerol), Chennai.
Duration : From July 15, 2010 to December 01, 2011.
Designation : Assistant Manager-Service

- Training, enquiry handling, CRM testing in service for diesel generators and inverters
- Technical Trainer for Engineering Trainees on 10 – 82.5 KVA Engines
- Technical Trainer in training the electricians on House Wiring, Inverters (250 KVA - 2 KVA) & Energy conservation methods

3.) Name of the Organization : C&S Electric Ltd.
Duration : From May 5, 2013 to July 5, 2013
Designation : Intern

Project: Study of 1 MW Solar Photovoltaic power plant installed at Nandha Village, bhiwani district, Haryana. The plant architecture, balance of system, technical details, plant maintenance & operation were studied, and performance of the plant and individual equipment's were analyzed and reported. Various Breakdowns and maintenance related problems were identified & studied.

Professional Experience

- 2020 Trainee, Professional Grant Development Workshop, Grant Training Center, University of Notre Dame
- 2019 Coordinator, Student Engagement Task Force, Connected Learning in Crisis Consortium
- 2017 Secretary, ENEGSA (Engineering Education Graduate Student Association), Purdue University
- 2017-2018, Communication committee chair, ENEGSA, Purdue University
- 2013 Research assistant, UNDP-GEP Biomass Program, UPES

- 2012 Project assistant, Exam-cell, Dr. MCET
- 2008 Secretary, AVERA, Department of Electrical Engineering, Dr. MCET

Teaching Experience

Graduate:

- 2017 ENE 554, Globalization and Engineering, Teaching Assistant, Purdue University

Undergraduate:

- 2016 ENGR 131, Transforming Ideas to Innovation, Teaching Assistant, Purdue University
- 2017, 2018, 2019 SA 10524, Research and Community Based Engineering Work (Study Abroad in Kenya), Co-Instructor, Purdue University
- 2017 ENGR 310, Engineering in Global Contexts, Co-Instructor, Purdue University
- 2017 ENGR 310, Engineering in Global Contexts, Co-Instructor, Purdue University
- 2018 ENGR 310, Engineering in Global Contexts, Co-Instructor & Online content developer, Purdue University

Informal Learning Space:

- 2016-present Tumaini-Tech Project, Engineering Skills Program at Tumaini Innovation Center (Alternative School for Street Youth), Co-Instructor & Program designer
- 2018, 2019 Introduction to Engineering at Kakuma Refugee Camp, Online Facilitator

Workshops as Facilitator:

- "Contextualized Teaching and Learning: Am Integrative Curriculum Model Utilizing Real-World Context" Workshop as a visiting scholar to Trefny Teaching and Learning Center, Colorado School of Mines
- "Student-Centered Learning." Part of the three-member facilitator team. Role included content development, design, facilitation and implementation. 5 workshops in Karnataka, Andhra Pradesh and Maharashtra (co-located with IUCEE Annual Conference), 2016.
- "Indian Student Forum." Organized, oversaw, and implemented student and student-professional workshops focusing on engineering and engineering education.
    - "Creativity and Innovation in Engineering Education for the developing India", Hubli, 2014
    - "Grand Challenges in Engineering", Bangalore, 2015
    - "Engineering Education without Borders", Pune, 2016
- "Engineering myths", "Test drive engineering", "The engineering dream shuffle", one-day workshops designed, developed, and implemented across various institutions in India as part of the Footsteps program.
- "Becoming your own boss", an entrepreneurship workshop for engineers. Designed, developed and implemented. Jaipur, 2015.

Grants

2019 USAID LASER PULSE ***(Submitted)***
Research and Translation of Socio-Emotional Skills Integrated in a "Localized Engineering" Program in Basic Education for Street Children in Western Kenya.

$267,912

2020 Shah Family Global Innovation Lab Seed Grant ***(Funded)***
Localized Engineering for GirlEngage Program in Zimbabwe with Plan USA
$40,649

2020 USAID ASHA ***(Confirmed for Funding)***
Jenga Engineers Project – Construction of Engineering Education Campus at Tumaini
$757, 383

2020 USAID Global Labor Initiative Concept note ***(Submitted)***
Participatory Design of Capacity Development via Digital Education for Women Laborers

2019 Fogarty Global Health Fellowship ***(Submitted)***
Investigating the Impact of a "Localized Engineering" and Residential Support Program in Western Kenya on the Mental Health of Street-Connected Children and Youth: A Mixed-Methods Study
Fellowship + $10,000

2019 NSF AISL ***(Unfunded)***
AISL Innovations in Development: Engaging Homeless/Unaccompanied Youth to Solve Community Engineering Problems
$2.3 million

2019 AMPATH Philanthropic OVC funds ***(Funded)***
From Vulnerability to Employability – Transitioning from OVC into Self-Sufficient Adults
$65,000

2019 NAE PEER Concept note ***(Unfunded)***
Pedagogical Practices Towards Acquisition of Social Emotional Skills among Higher Education Students in Kakuma Refugee Camp, Kenya.

2019 Youth Activity RFI to USAID
Response to Request for Information for the USAID Kenya and East Africa Youth Empowerment Activity

2015 I2D Seed Grant **(Funded)**
Engineering Skills Curriculum and Digital Materials for Out of School Youth
$70,000

Awards and Leadership Positions

- 2018 Graduate Teaching Certification, Center for Instructional Excellence, Purdue University
- 2017 Graduate Student Teaching Award, School of Engineering Education, Purdue University

- 2016 Global Student Forum Chair, Seoul
- 2015 Explorers Fellowship, Purdue University
- 2014 IGIP-SPEED Young Scientist award
- 2014 Indian Student Forum Chair, Hubli
- 2012–2014 elected Vice President for SPEED (Student Platform for Engineering Education Development)
- Best Student of the Year, ISTE Awards, 2010
- 2009-2010, President -Students Guild of Service, Dr.MCET

Competencies:

Languages: English, Tamil, and Hindi

Software:

Programming: XML, C

Research analysis: R, NVIVO

Design: SketchUp, FlashPrint

Energy Analysis: PV Syst, RET International, HOMER