Issues of Identity and Equity in STEM Education

STEM Teachers Identity and Gender Equity in STEM

A DISSERTATION
SUBMITTED TO THE FACULTY OF
UNIVERSITY OF MINNESOTA
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF EDUCATION

Gillian H. Roehrig, Advisor

December, 2018

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Acknowledgements

First, I would like to deeply thank my advisor, Dr. Gillian Roehrig. Without her support, I never would have started and completed this journey. She has provided me with all the support I needed to develop as a scholar and researcher. Her confidence in my abilities without limits from the start of my program at the University of Minnesota, and for that, I am forever grateful. She has not only been an advisor, but a mentor that has guided me through the sometimes-thorny way of academia and research.

Second, I would not have been able to complete this project without all the students and teachers, Egyptian and American, who I conducted the qualitative interviews with. They welcomed me and were ready to provide input on whatever topics and/or issues I discussed with them. I was extremely pleased to work with all of them in the three studies that comprise this research endeavor.

Third, I would like to thank Felicia Leammukda for her wonderful support especially in the first study on the developing identities of teachers at emerging STEM schools. She conducted the interviews and helped in transcribing them and editing the paper. I am deeply grateful for her support.

Fourth, my committee who were not only reviewing and providing feedback on my work but have been my guides all through different stages of the program at the University. without their wonderful support, I would not have been able to finish in time.

Finally, I'd like to thank all the administrative staff at the STEM Education Center. Thank you to Christine Slattery for continuing to put up with my requests over the past two years. I cannot forget how Kristina Pearson was so helpful in this journey.

I owe all the STEM graduate students for their support at all times. Special thanks to Robert Palmer, Illana Livstrom, Ramya Sivaraj, Hillary Barron, Foster Graif, Beth Crotty, Karl Jung, and Beth Ring.

Dedication

This dissertation is dedicated to the soul of my father who passed away while I was in my second year in my PhD program and could not go back to Egypt to bid him a farewell. It is also dedicated to my nucleus family: my wife, Reda, and my children Hadeer, Amir, and Ahmed who have continued to be my biggest fans and have encouraged me to go after my dreams. Their endless love and support has allowed me to be where I am today.

Abstract

This three-paper dissertation addresses issues of equity and identity in STEM education through three studies conducted with teachers in two emerging STEM schools in the Midwest United States (U.S.), graduates of a girls STEM school in Egypt, and the teachers of a STEM school in Egypt. The studies comprising this dissertation utilized case study as a research design to explore the issues of equity and identity in STEM education. Participants in each study were selected using criterion purposeful sampling. Though these studies were not intended to be comparative, the results of the three studies reveal context-based results with several global assumptions regarding nature of STEM education and the pertinent issues of equity and identity. In the three studies STEM education is viewed as having a transformative power for both teachers as providing an opportunity for change at the professional level; and for female students providing an equitable learning environment for girls aspiring to pursue STEM fields. The evolving nature of the STEM teacher identity was evident across all cases. The American teachers conceptualize STEM as providing valuable tool for better learning opportunities for students based on integrated curriculum and with emphasis on equity and inclusion. Egyptian teachers viewed STEM from two lenses: as a pedagogical tool to facilitate learning complex concepts, and a system level reform initiative to reform the existing failing education system in the country and prepare students for the labor market. Characteristics of STEM teachers were uniform across the three studies; flexibility, collaboration and open to change. The challenges for teachers' identity development in the Egyptian experience are mostly related to lack of resources and bureaucracy while in the U.S. case they are more connected with professional development and time needed

for more practice. While the studies making up this dissertation denote the centrality of the context regarding STEM design and implementation, they still have implications for STEM education as a global reform initiative. For separate abstracts for each study see Appendix D.

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Chapter 1

Introduction

Organization of the Dissertation

Overview of the chapters. This dissertation represents a three-paper dissertation which contains six chapters. Chapter 1 provides an overall organization and rationale for the dissertation. Chapter 2 contains a general literature review that serves to ground the proposed studies in the context of prior research. Chapters 3, 4, and 5 each contains a single study, where each chapter includes a rationale/introduction, brief literature review, and methodology specific to that study. Chapter 6 will discuss central findings from all three studies as well as implications for teaching and future research.

Chapter 3 contains the study in which the new roles and identities for teachers in emerging STEM schools are explored. These roles and identities has remained an ill-defined area in STEM. In this paper, the question, 'How do teachers define their roles as STEM teachers within a STEM school?' is explored through a grounded theory approach within a multiple case design. Data for this study were drawn from semi-structured interviews conducted with teachers from two developing STEM schools within a large urban district in the Midwestern United States. Teams of teachers at each of the schools worked throughout the year to develop and implement their vision for STEM. Using an inductive data analysis process, three major themes that characterize a STEM teacher identity emerged. These are the nature of STEM teachers' identity; professional characteristics of STEM; and personal characteristics of STEM teachers. This study concluded that STEM teachers' identity as an evolving process can be described as a "marathon" not a "sprint." An alignment between teachers' personal philosophy and

STEM understanding is essential for the success in teaching in STEM schools. Collaboration, flexibility, awareness of students' needs and the community at large were identified as pivotal characteristics of STEM teachers. Implications of this study include its contribution to the literature related to teachers' identities and roles in a STEM school and helping develop a decision making process on levels of teacher preparation, recruitment, and professional development for those working or preparing to work in STEM schools.

Chapter 4 contains the study in which the gender gap in STEM education was explored in the context of an Egyptian STEM school for girls. An intrinsic case study design was used to explore the experiences of girls in STEM from a socio-cultural perspective within a critical theory framework. The participants in this study were STEM school graduates currently enrolled in engineering tracks in higher education institutions in the United States. Though STEM fields, especially engineering, are stereotyped as male dominated fields, Egyptian girls at a Cairo single-sex STEM school pursued study and future work in engineering and science fields. Open-ended semi-structured interviews were used to gather data and an open and axial inductive approach was used to analyze the data. Findings support the assumptions that gender gap in STEM education in Egypt is probably larger in scope than being an inherent gender deficit problem or formal discriminatory issue. Girls' choice of education and work tracks are deeply influenced by their childhood background, family education level, socioeconomic status, and personal factors like self-efficacy and resistance. At school level, teachers' support, challenging STEM curriculum, dynamic formative assessment, student-centered pedagogies, female-friendly teaching approaches, and a positive school environment played a great role in

developing Egyptian female students' potential to pursue STEM fields in higher education institutions.

In the third study, in chapter 5, the professional journey of Egyptian STEM teachers in a girls' STEM school was explored. The study was initiated as a response to the growing STEM experience in Egypt both in terms of the growing number of schools, number of students admitted, and the effect of this experience on the overall education system in the country. Viewing teachers as the backbone of the STEM experience and teaching as a relational sociocultural practice (Biesta &Stengel, 2016), this research probed the change and development that occurred for the Egyptian STEM teachers over the course of their work in a STEM school. Using a multiple holistic case study design and inductive and deductive data analysis of semi structured interviews with teachers, teachers lesson plans, document review of Ministry of Education decrees, and reports of Education Consortium for the Advancement of STEM in Egypt, teachers were found to have undergone a deep transformative change process from traditional mindset and approaches into teachers with progressive mindset and different student-centered classroom practices. The teachers developed different conceptualizations of the STEM education, stressed the importance of collaboration, critical thinking and motivation for teachers seeking to work in a STEM setting, and considered themselves moving towards established STEM teachers' identity. Despite several challenges like limited resources, creeping of some ailments from the traditional system like bureaucracy, and private tuitions; the teachers still possess the energy for continuing irreversible professional growth that eventually would have an impact on the larger context of the Egyptian education system.

Rationale

In the last few decades, science, technology, engineering, and mathematics (STEM) education has been at the forefront of educational reform initiatives not only in the United States but around the world (English, 2016; Kelley and Knowles, 2016; Ritz & Fan, 2015). STEM features prominently among current educational priorities, primarily driven by workforce issues. According to projections made by the Bureau of Labor Statistics (United States Bureau of Labor Statistics, 2014), there will be about 1 million more openings in STEM-related occupation by 2022 than there were in 2012. In the 2017 report, employment in computer occupations is projected to increase by 12.5 percent from 2014 to 2024, and due to its large employment size, this growth is expected to result in nearly half a million new jobs, far more than any other STEM group. The group projected to add the second largest number of new jobs from 2014 to 2024 is engineering occupations, with 65,000 new jobs (United States Bureau of Labor Statistics, 2017).

On an equity level, the low representation of female students in STEM fields, especially physical sciences and engineering, and how to overcome this gender gap still poses a big challenge for educators and researchers (Dare, 2015; Schellinger et al., 2018). The most recent statistics show significant gaps in female representation in STEM fields. In the US, for instance, women earned 57.3% of bachelor's degrees in all fields in 2013 and only 50.3% of both science and engineering bachelor's degrees. However, women's participation in science and engineering at the undergraduate level significantly differs by specific field of study. While women receive over half of bachelor's degrees awarded in the biological sciences, they receive far fewer in the computer sciences (17.9%),

engineering (19.3%), physical sciences (39%) and mathematics (43.1%) (NSF, Science & Engineering Indicators, 2016).

In the Egyptian context, the picture is not much different. Official figures show that female's share of workforce (based on the Higher Education degrees they have) has not exceeded 24.2% in 2016 and the female participation is overwhelmingly present in the fields of education, public health and social work which are viewed as female-friendly fields while having the least representation in engineering (CAPMAS, 2017; Krafft & Asaad, 2015). Understanding this gap especially in the Egyptian context and exploring the role of STEM as an educational reform model in helping narrow the gender gap in STEM is a timely topic on the research agenda.

This increasing interest in STEM parallels universal calls for improved educational practices in the classrooms, providing equitable STEM education opportunities for all (e.g., Dare, 2015; Mendoza, Moemi, & Cox, 2012; Peters-Burton, 2018), preparing graduates equipped with the 21st century skills (Gonzalez & Kuenzi, 2012; Piburn & Sawada, 2000), and creating a STEM literate society (Bybee, 2010, 2013). Bybee (2010) considers the overall purpose of STEM education is to further develop a STEM literate society. STEM literacy refers to the knowledge, attitudes, and skills necessary to recognize questions and problems in life situations, explain the natural and man-made phenomena, and draw evidence-based conclusions the issues related to STEM fields (Bybee, 2010, 2013; OECD, 2006). In other words, STEM literacy needs to consider three levels: (1) literacies of science, technology, engineering, mathematics, and other associated areas; (2) personal, societal, and economic needs; and (3) cognitive, affective, and psychomotor learning domains (Zollman, 2012, p.15). There is a need to

understand STEM disciplines as forms of human knowledge not just the work of scientists and engineers who use inquiry and design to solve problems. Students are guided through the learning process to show their "awareness of how STEM disciplines shape our material, intellectual, and cultural environments; and willingness to engage in STEM-related issues and with the ideas of science, technology, engineering and mathematics as a constructive, concerned, and reflective citizen" (Bybee, 2013, p.101; Fisher & Frey, 2014). There is research evidence that project based learning in STEM schools "benefitted low performing students to a greater extent and decreased the achievement gap" (Han, Capraro, & Capraro, 2015, p. 1089) and may support elementary students' science content knowledge, while helping students learn to design, construct, and test solutions to engineering problems (Wendell, & Rogers, 2013).

Accordingly, in an effort to prepare twenty-first-century citizens who are informed consumers and producers of STEM knowledge, different reforms have been introduced to the formal STEM education system, and science education in particular. These include, but are not restricted to, the development of science standards, designing and implementing different professional development programs in STEM, which in the United States have culminated in the production of the Next Generation Science Standards (Dani, Hartman, & Helfrich, 2017; NGSS Lead States, 2013).

One of the basic assumptions upon which STEM education builds its rationale as a pedagogical reform approach is that better learning in science and mathematics takes place when they are integrated in curriculum where disciplinary concepts are used to address real world problems within an engineering context (e.g., Bybee, 2013; English, 2016; Morrison, 2006). However, there is not one uniform conceptualization either of

STEM as an educational model or pedagogical approach, or the nature of STEM integration (Bybee, 2013; Guzey, Moore & Harwell, 2016; Roehrig, Moore, Wang, & Park, 2012). Even among the researchers and educational professionals most heavily involved in the STEM movement, there appear to be numerous ways to define both the term and the practice of STEM education, and roles of teachers. Without understanding of the conceptions of integrated STEM education held by practitioners, or how these conceptions influence the development of integrated STEM curriculum or the implementation of integrated STEM curricula in the classroom, supporting the STEM movement will be difficult. Likewise, teachers, whose role is so critical for the success of STEM integrated curricula both in design and implementation, develop different conceptualizations of both STEM and what integration looks like (Guzey et. al, 2016; Herschbach, 2011; Kelley& Knowles, 2016; Ring, Dare, Crotty & Roehrig, 2017). Teachers are torn between their roles as science, mathematics, and social studies teachers and their newly born identities as STEM teacher and what that really means (Sanders, 2009, Williams, 2011).

Taken together, understanding the roles and characteristics STEM teachers have or should have and identifying the best environment for an equitable STEM experience for all is an important step in implementing reforms that call for increased integrated STEM in K-12 schools. How teachers conceptualize their roles and identities in a STEM setting and enact these in their classrooms and how female students provide insights on the elements of a successful STEM experience will probably contribute to meeting the lofty goals of STEM as an educational reform initiative set forth by the educational policy makers in Egypt and elsewhere.

In this three-paper dissertation, I have explored the nature of STEM integration with specific emphasis on the role of teachers in designing and implementing integrated curriculum, the nature of teachers' roles and characteristics in STEM settings, and finally the issue of gender equity in STEM education. This inquiry was partially done in the United States and completed in Egypt providing an international perspective on STEM issues. The following chapter provides a more detailed literature review related to each of the three studies which are included as chapter 3-5 of the dissertation.

Chapter 2

Literature Review

The STEM education movement has great momentum in different parts of the world (English, 2016; Kelley and Knowles, 2016; Ritz & Fan, 2015). The complexities that characterize local and global grand challenges, such as poverty, pollution, and energy shortages, necessitate a different perspective to education that takes into account alternative pathways to find solutions to these challenges and provide a meaningful educational experience to learners (Bybee, 2010, 2013; Honey, Pearson & Schweingruber, 2014). These pathways require the integration of multiple STEM concepts to solve these interconnected and clustered challenges (Moore, Tank, Glancy, Kersten, Smith & Stohlmann, 2014; Honey et. al, 2014).

The STEM movement started as a response to non-educational needs - social and economic in nature (Breiner, Johnson, Harkness, & Koehler, 2012; English, 2016; Sanders, 2009) which were spurred on by the global financial crisis. It was hoped that coordination and integration of STEM activities would better equip a workforce for dealing with the contemporary nature of business and industry, and encourage more school leavers to seek further training and employment in areas of engineering and science (Mendoza, et al., 2012; William, 2011). However, many definitions of STEM exist and this lack of agreement amongst researchers and practitioners are problematic in terms of implementation of STEM as an educational reform (Breiner et al., 2012; Johnson, 2012).

Although educators are aware of the importance of STEM education, neither educators nor researchers consistently agree on what STEM education should really be

about in K-12 education or what the nature of integration should look like (Breiner, Johnson, Harkness, & Koehler, 2012). The challenge in defining STEM education at the K-12 level with a unitary definition may be the product of poor understanding of the philosophical grounding of STEM (Chesky & Wolfmeyer, 2015) reducing it, in some cases, to a simplistic version of "design cycles" based hands-on activities at the elementary school level (Williams, 2011).

Integrative STEM education is grounded in the tenets of constructivism and the findings of cognitive science. Bruning, Schraw, Norby, & Ronning (2004) identified the following set of cognitive themes that resonate with integrative STEM education:

- Learning is a constructive, not a receptive, process.
- Motivation and beliefs are integral to cognition.
- Social interaction is fundamental to cognitive development.
- Knowledge, strategies, and expertise are contextual.

Applying these cognitive themes to the integrated STEM activities and strategies would reveal that STEM practices are constructive in nature and conducive to better learning (Sanders, 2009). STEM practices provide context and a framework for organizing abstract understandings of science and mathematics and encourage students to actively construct contextualized knowledge, thereby promoting recall and learning transfer (Ambrose, 2013; Sanders, 2009). STEM education pedagogy is inherently learner-centered and knowledge-centered, and when used with groups of learners, provides a remarkably robust environment for the social interaction so critical to the learning process (Hutchison, 2012; Moore et al. 2014; Sanders, 2009).

Introducing Engineering. The introduction of engineering into K-12 education has been a major driver of integrated STEM as it provides a context for integration to place in a rigorous way (Herschbach, 2011; Lachapelle & Cunningham, 2014; Roehrig et al., 2012). Higher education institutions and professional associations strongly support incorporating engineering in the high school curriculum, either as a course on its own or woven into existing mathematics and science courses (Carr et al., 2012). Common arguments for K-12 engineering education support the educational value of building curricula that provide (e.g. Ambrose, 2013, p. 16-17):

- context and continual integration across time and courses that promote transfer of existing knowledge and skills to new contexts;
- early exposure to engineering and engineers to lay the foundation for future learning;
- meaningful engagement at the most auspicious time to promote deep learning;
- opportunities for reflection to connect thinking and doing;
- development of students' metacognitive abilities to foster self-directed, lifelong learning skills; and
- authentic experiential learning opportunities to put theory into practice in the real world.

Models of STEM integration

Definitions and requirements. Various conceptualizations and definitions have been in use since the inception of integrated STEM. One common thread among these is

that STEM is viewed as a “meta-discipline” and this means the “creation of a discipline based on the integration of other disciplinary knowledge into a new ‘whole’ rather than in bits and pieces (Ejiwale, 2013; Kelly & Knowles, 2016; Merril, 2009; Moore et. al, 2014). It is an interdisciplinary approach (e.g., Merril, 2009; Morrison, 2006) to learning by integrating the four disciplines into one cohesive teaching and learning paradigm. This integration is aimed at the removal of the traditional barriers erected between the four disciplines (Morrison, 2008). In other words, STEM education can be defined an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy (Tsupros, Kohler, & Hallinen, 2009). High quality STEM programs outlined by Kennedy and Odell (2014) should include (1) integration of technology and engineering into science and mathematics curriculum at a minimum; (2) promote scientific inquiry and engineering design, include rigorous mathematics and science instruction; (3) collaborative approaches to learning, connect students and educators with STEM fields and professionals; (4) provide global and multi-perspective viewpoints; (5) incorporate strategies such as project-based learning, provide formal and informal learning experiences; and (6) incorporate appropriate technologies to enhance learning; (7) offered through both formal and informal learning experiences; (8) present a balance of STEM by offering a relevant context for learning and integrating STEM core content knowledge through strategies such as project-based learning. (p.255).

Moore et al. (2014) present a seminal framework for quality STEM education having six key elements that are required for meaningful integrated STEM teaching and learning. First, a unique feature of an integrated STEM curriculum is the use of a motivating and engaging context, which helps students make sense of the unit activities that are based on extensions of their own personal knowledge and experiences. The context of the curriculum needs to include a compelling purpose and involve current events and/or contemporary issues so that students can apply engineering processes in personally meaningful, partially or completely realistic situations. Second, the STEM unit should allow students participating in engineering design challenges to learn about engineering design processes and engineering practices. A good engineering design challenge allows students to explore or develop technologies to solve the problem and requires students to consider constraints, safety, risks, and alternative solutions. Third, learning from failure is a critical part of an engineering design process and student learning. Fourth, the integrated STEM unit includes grade level appropriate science and mathematics content. Students participate in activities that allow them to learn, understand, and use fundamental science and mathematics concepts to solve the engineering challenge. Fifth, the lessons and the activities in an integrated STEM unit should be student-centered. Previous research has shown that students develop deeper understanding and skills through active participation in learning activities. Specifically, project-based or problem-based approaches provide great opportunities for students for conceptual learning of complex systems and science concepts. Sixth, teamwork and communication have to be at the core of the STEM activities. Students should work in teams to complete the engineering challenge and other science or mathematics activities as necessary. Students need many opportunities to be

involved in teamwork to improve their teamwork skills since it is a critical 21st century skill. The unit should foster communication skill development as well. Students need to communicate science concepts, mathematical thinking, and engineering thinking. Together, these six elements help to ensure a useful integrated STEM learning environment promoting student learning (Guzey et. al, 2016, 2016; Moore et al., 2014). However, research shows different forms and degrees of integrations are implemented in classrooms.

Models of integration. The degree and/or level of integration depends on different aspects including – but not restricted to- the context in which the integration experience takes place, the experience of the teachers who design and implement the integrated curriculum, and the purpose of integration (Bybee, 2013; Fogarty, 1991; Harden, 2000). Following is a brief description of different perspectives of STEM curriculum integration.

Bybee (2013) presented nine models (perspectives being used in the field) for STEM integration. These can be summarized as follows: (1) single discipline reference where STEM equals science discipline; (2) STEM as reference for science and mathematics where separate disciplines of science and mathematics are emphasized and engineering and technology in the shadow; (3) science discipline incorporating other disciplines as appropriate; (4) STEM as giving separate general introductions to the four disciplines as four separate courses; (5) STEM as science and mathematics are connected by one technology or engineering program; (6) STEM as coordination across disciplines utilizing concepts and processes across boundaries of separate disciplines; (7) STEM as combining two or three disciplines to form a course; (8) STEM as complementary overlapping across disciplines as integrated by sequencing disciplines in units or courses; and (9) STEM as

transdisciplinary course or program to major issues where students work on a separate project (capstone) to solve problems.

Herschbach's (2011) used McNeil's (1990) curriculum model to suggest two integrative models for STEM; correlated design or broad field. In correlated design corresponding to Bybee's (2013) models four through six in which each subject retains its unique identity with a little adaptation to meet the requirements of an overarching theme. However, in this case, more coordinated planning is a must to ensure synchronized learning opportunities for students. In the broad field curriculum model corresponding to Bybee's (2013) models seven through nine, a cluster of related but different subjects is organized into a single area of study which can be achieved through different kinds of activities and problem-solving tasks (Herschbach, 2011; McNeil, 1990) such as capstone projects that are designed for take place over one semester or academic (Morrison, 2006).

Both Herschbach (2011) and Bybee (2013) provide related models that can be seen along a continuum starting from isolated disciplines to the most complex interdisciplinary work. In other words, STEM can be seen as a flexible or fluid education system (Kelly and Knowles, 2016) where different types of STEM are adopted in different schools for different purposes. This fluidity may be viewed as a good thing that might help under-resourced school to try as much STEM as they can and still be called a "*STEM*" school as they start the journey for being full-fledged STEM school.

In summary, STEM represents a paradigm shift for most teachers—giving up the compartmentalization of STEM content areas and moving toward the natural integration of disciplines resembles the challenges we have in the real world; the way scientists and engineers think and use different content knowledge to solve problems (Johnson, 2012;

Morrison, 2006). Thinking of STEM as an integrated approach towards a rigorous learning experience made up of the concepts, skills, and higher order thinking that bind or link the STEM disciplines together, then the STEM acronym – as a meta-discipline- takes on a meaning beyond simply the sum of its parts (Ejiwale, 2013; Moore, et. al, 2015).

Challenges to STEM education

In spite of the need and rationale for STEM education, it is not an easy transformation for schools and teachers (Guzey et. al, 2016; Kelley and Knowles, 2016). There are different challenges and barriers to creating and implementing a robust integrated STEM curriculum (Ejiwale, 2013; Mendoza, 2012). These include epistemological constraints (Johnson, 2012; Sanders, 2009), lack of well-prepared and qualified teachers to help both design and implement STEM integrated curriculum, lack of curricular materials and resources, and the lack of alignment between content to be taught in different disciplines (Ejiwale, 2013; Guzey et. al, 206; Ruggirello, & Balcerzak, 2013; Slavit, Nelson, & Lesseig, 2016),

Epistemological constraints. The four STEM fields have epistemological characteristics that differ markedly. These characteristics must be fully recognized and accommodated in planning and teaching in order to preserve the intellectual integrity of each field. Otherwise, a very limited understanding undervalues specific intellectual contributions or ignores the collective value of each (Herschbach, 2011; Williams, 2011). These epistemological constraints are important to study 1 and detailed in chapter 3. In order to avoid the epistemological impasse, different formats and models were introduced so that a context is provided that the integrated curriculum looks seamless and natural. Kelly and Knowles (2016), for instance, argue that integrated STEM curriculum should be created in the context of the situated cognition theory using the engineering design, science inquiry,

and technology as a value laden instrument serving cultural and economic purposes as ideal content integrators in order to provide opportunity to transfer science knowledge to authentic situations.

Polarity towards science. Another challenge is concerned with the status of disciplines like mathematics and technology (English, 2016; Sanders, 2009); questions like "what do we mean by technology?" and "how mathematics can be made meaningful in STEM integrated curriculum?" are still unanswered (Sanders, 2009; Williams, 2011). Science is, in this sense, taking the lion's share of emphasis causing what might be called "polarity effect" of STEM integration (Roberts & Cantu, 2012) where in many circumstances the STEM integrated units are strikingly leaning towards science (Herschbach, 2011; Williams, 2011). The NGSS, for instance, are ultimately science standards, where an attempt to introduce engineering practices and cross-cutting concepts to the disciplinary core ideas is considered the corner stone in the emerging STEM movement. (NGSS Lead States, 2013). In addition to that, most problems posed to students in STEM settings are derived from everyday life issues with natural sciences underpinning (National Research Council, 2011; Roberts & Cantu, 2012).

Ready qualified teachers. STEM as a reform pedagogical and/or curriculum movement cannot yield positive results in the absence of a change in teaching practices in the classrooms. In other words, reformed curriculum should be accompanied by changes in teaching approaches. "When reformed teaching is used, students learning is significantly enhanced" (Sawada, 2002, p.251). The various proposed STEM integration models and the resources allocated to implementation require significant professional learning to put in place qualified STEM teachers (Hutchison, 2012; Ruggirello, & Balcerzak, 2013; Slavit et

al., 2016). The sophisticated role of STEM teachers requires much work on different levels including policy levels, and teacher preparation institutions levels (Hutchison, 2012; Ruggirello, & Balcerzak, 2013). STEM teachers need deep content knowledge in STEM and strong pedagogical skills for teaching their students (Ejiwale, 2013; Hutchison, 2012, Slavit et. al, 2016). Unfortunately, not many teachers in STEM classrooms possess these attributes (Guzey, et. al, 2016). In addition, teachers should be motivated to participate in professional development to help them achieve deep STEM content knowledge and mastery of STEM pedagogy ((Ejiwale, 2013; Hutchison, 2012; Morrison, 2006).

Therefore, there is a need to work towards preparing and retaining qualified STEM teachers and provide them with systematic professional development (Hutchinson, 2012; Johnson, 2012). In this way, compatibility between STEM integration as a curricular reform initiative and teachers' innovative pedagogies would be created (Johnson, 2012). However, as a result of poor funding for teacher development, professional development has become nothing more than a hoop to renew a license rather than a valued means of staying relevant to the times and meeting the needs of students ((Ejiwale, 2013; Hutchison, 2012; Johnson, 2012). By extension, it becomes hard to find a STEM teacher who is an ongoing learner, risk-taker, inquirer, curriculum designer, negotiator, and collaborator. (Slavit, Nelson, & Lesseig, 2016).

In addition, the identity of the teachers working in STEM schools or "STEM teachers" reflects another level of fluidity regarding what makes a STEM teacher. One model advocates having single teacher taking over an integrated STEM curriculum unit. In this model, a STEM integrated unit is developed – maybe with the help of other resources and experts- and implemented by one teacher who is required to be able to work across

disciplines (Sanders, 2009). Another model denotes a group of teachers team-teaching a STEM curriculum in a coordinated manner (Herschbach, 2011; William, 2011). In this model, high levels of collaboration and coordination are required so that those teachers can seamlessly teach the intended STEM curriculum (Herschbach, 2011). The question is how existing science, mathematics, social studies and other teachers develop their identity as STEM teachers in a STEM setting corresponding to these models.

Teacher identity

Research on identity has been a growing domain in the contexts of teacher education. It provides a comprehensive and sophisticated picture of what it means to be a teacher, exploring the multiple influences that shape teacher identity, including personal experiences, media images, and personal and pedagogical beliefs (Franzak, 2002). There are different conceptualizations of teacher identity. Watson (2006) argues that teacher identity should be viewed as a teacher's sense of self as a teacher, which encompasses one's personal, professional, socio-political, and cultural dimensions. Other researchers view teacher identity as related to central aspects of teachers' professional lives: their conception of the teacher role, motivation for teaching, choice of teaching methods, willingness to change, and the trajectory of their professional learning and development (Beijaard, Meijer, & Verloop, 2004; Beauchamp & Thomas, 2009; Olsen, 2014). In this sense, teacher identity is considered a dynamic, continually changing, and active process which develops over time through interaction with different policy, school, and classroom environments and those who work in them. In other words, teacher identity is looked upon as a social practice highlighting how a teacher's self is made, and continually re-made, inside the flow of contextualized practice (Buchanan & Olsen, 2018).

Based on their survey of previous literature, Zembylas and Chubbuck (2018) reported on four key aspects of teacher identity: emotion, narrative and discourse, reflection, and agency and structure. These four aspects portray a multifaceted picture of teacher identity.

Emotion. Emotion and teacher identity are believed to be interrelated and dynamic as teachers express emotions of care and support that are guided or shaped by their professional identity especially salient in the politicized context of school reform efforts (Darby, 2008; Lasky, 2005). The emotions experienced in the ongoing construction of teachers' professional identities are deeply connected to their personal beliefs and attitudes which are, themselves, entangled in the sociopolitical context of their workplace (Zembylas & Chubbuck, 2018).

Discourse and narrative. The literature on discursive/narrative construction of teacher identity is grounded in sociocultural research (Beauchamp & Thomas, 2009) emphasizing the multiplicity, discontinuity, and social nature of identity (Akkerman and Meijer, 2011). First, the multiplicity of identity denotes involving 'sub-identities' in which a teachers' professional identity consists of sub-identities relating to teachers' different contexts and relationships. Second, the discontinuity of identity as being 'an ongoing process of construction' in which teacher identity is described as fluid and shifting from moment to moment and context to context (Beauchamp & Thomas, 2009). Third, the social nature of identity which relates to various social contexts and relationships in which teachers' identity develops in social, communicative contexts and for socially significant reasons (Alsup, 2006). In other words, teachers position themselves/ their identity in relation

to students, other teachers, teacher educators, discourses from programs, schools, and national images—all relational stances which can implicate power relations.

Discourse—literally the talk within and among teachers—both constitutes identity and is itself constituted through identity (Cohen, 2010). Therefore, narrative is seen not only as a reflective practice of teachers but as a manifestation of discourse, both within the teacher and in the institutions/national sociopolitical contexts in which they are located (Søreide, 2006) which consolidates the assumption that discursive identity formation is dialogically relational (Akkerman & Meijer, 2011; Watson, 2006).

Reflection. The role of reflection is seen as multiple factors emerge: prior personal identity, significant community membership, mentoring support, and reflection on actual practice versus theory (Korthagen, 2004). In this sense, teacher identity formation is reinforced through the process of reflection on teachers' interaction on three levels: conflict and discomfort, multiple trajectories of past and future experiences, and context of reflection (Smith, 2007; Zembylas & Chubbuck, 2015). Reflection on identity is provoked and enriched at sites of conflict and discomfort, such as the dissonance between one's self-image and how one is perceived by others. Identity development, also, occurs through reflection on multiple trajectories/ images of past experiences and future possibilities, such as "drawing on the past and imagining futures" (Smith, 2007, p. 383). Finally, the context of reflection influences identity formation (Zembylas & Chubbuck, 2015) denoting the different factors the teachers interact with including, among other things, the type of curriculum, the requirements for success, school vision, kind of students, and the social and cultural environment. In an effort to organize this complexity into a more coherent framework of teacher identity to support professional development, Korthagen (2004) proposed a

multilayered model where reflection on "core" layers of identity—mission/identity/beliefs—significantly influences the more outer layers competencies/behaviors/environment. Thus, the internal elements of identity can dictate more external practices (Korthagen, 2004).

The tension between agency and structure. Agency, the belief in one's capacity to achieve their goals, denoting inherent cognitive and emotional qualities as the source of such capacity (Beauchamp & Thomas, 2011; Day et al., 2006). Structure, in contrast, means there are external influences shaping that process of gaining achievement. The tension between agency and structure in teacher identity development can be exemplified in the argument over whether teachers are "born" or "made" (Schepens, Aelterman, & Vlerick, 2009). This distinction between teacher identity derived from personal agency and that derived from structures that support becoming a teacher is an important one since it implicates the nature of who may become an effective teacher and even the nature of the teaching process itself. Additionally, this aspect positions the personal (agency) in reciprocal interaction with the social and cultural (structures).

Taken together, these theories indicate that developing a teacher identity denotes an ongoing process of construction through professional life that includes social, personal, and professional experiences that happen over an extended time span (Cooper & Olson, 1996; Rogers & Scott, 2008). Therefore, teacher identity research takes into consideration professional, personal, academic, and social aspects, in addition to teachers' roles at schools (Beijaard, Meijer, & Verloop, 2004). In addition, identity development indicates that development is far from a linear process (Flores & Day, 2006; Geijsel & Meijers, 2005). Teachers' identity formation is viewed as a dialogic process between the external and internal factors affecting the teachers' work; it is not only about the accumulation of "assets"

or experiences that a teacher acquires throughout his/her career but allows for an understanding of how teachers themselves make sense of their teaching practice (Niessen, Widdershoven, Abma, Van der Vleuten, & Akkerman, 2008), thus opening the door for considering inherent personal dimensions as an integral element in the identity formation process. In brief, teacher identities can be looked upon as a shifting combination of personal attributes, culture, social influence, and institutional values which may change according to role or circumstance (Day et al., 2006).

Gender Equity in STEM

Statistics and research reveals the existence of a gender gap in STEM fields worldwide with variation from country to country (AAUW, 2000, 2010; Clewell & Campbel, 2002). Researchers have been investigating the reasons behind the gender gap in STEM fields for decades (e.g., Ahqlavit et al., 2013; AAUW, 2000; Belenky, Clinchy, Goldberger & Tarule, 1997; Baker et al., 2007). Answers have varied along a continuum that spans from biological and cognitive reasons, socio-cultural reasons up to idiosyncratic ones.

STEM education, by definition, encompasses different aspects that should promote social justice and gender equity including, but restricted to, using differentiated instruction (e.g. students do research, do hands on, individual and collaborative tasks), linking classroom practices and content to the outside environment (e.g. working on local or global grand challenges of the environment), utilizing inquiry and critical thinking skills, and use dynamic formative assessment modes (Avery, 2013; Peters-Burton, Lynch, Behrend, & Means, 2014; Peters-Burton, 2018). Garces and Espinosa (2013) argue that greater diversity in STEM fields not only sets the stage for a robust 21st century workforce but also

contributes to educational and research environments that reflect and draw on diverse perspectives for stronger science suggesting that access and exposure to college environments and supportive role models and mentors can make a world of difference for expanding access to STEM fields, and show *all* students that the path to a STEM career is achievable in order to overcome the different stereotypical deficit issues.

Erin Peters-Burton (2018) advocated for STEM as a valid means for achieving social equity in education; "if STEM education can include more students and open opportunities for students [all students regardless of gender, race, etc.] who were not even aware of a STEM way of knowing, maybe we can nudge closer to an equitable society." (p.74). However, gender gaps have persisted in the STEM fields for decades.

Different pathways have been suggested to overcome the gender inequity in STEM fields including personal attributes such as self-efficacy (Bandura, 1977) that can be one way to overcome the stigmatized stereotypes of seeing girls and women not compatible for science and engineering fields (Ahlqvist et al., 2013; Nosek et al., 2009), at-school-level female friendly instruction (Dare, 2015; Rosser, 1993) and providing a safe environment for learning like the controversial same sex school settings (AAUW, 2000; Datnow & Hubbard, 2002; Riegle-Crumb, Farkas, Muller, & Chandra, 2006). For in-depth discussion on gender equity in STEM, see chapter 4.

Chapter 3

Developing Identities of STEM Teachers at Emerging STEM schools

Introduction

In order to continue to lead in almost all fields in this globalized world, the United States needs to have high-quality STEM education (Gonzalez & Kuenzi, 2012). However, since the late 1980s, there have been alarming signs that the U.S. is lagging in performance in international tests, especially in mathematics and science (Forman, et al., 2015; Honey et al., 2014). The most recent results show that the United States experienced a three-point drop in average score in mathematics, while remaining relatively flat in reading and science compared to countries of the Organization for Economic Cooperation and Development (OECD) that participated in the 2015 Programme for International Student Assessment (PISA) (OECD, 2016). In response to previous similar reports, policymakers have called for integrated approaches to K-12 STEM education using authentic learning experiences (National Center on Education and the Economy, 2007) to prepare students for the highly competitive 21st century with new mindsets and skills (Breiner, Johnson, Harkness, & Koehler, 2012; Bybee, 2010; Morrison, 2006; Roberts & Cantu, 2012). Consequently, calls for integrating engineering into the K-12 education system, as well as initiating a multidisciplinary framework for in- and out-of-school learning, were the driving force for developing the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013).

In spite of the urgency to improve K-12 STEM education at the federal, state, and local levels (Forman et al., 2015) and internationally as well (Ritz & Fan, 2015), there has been a sense of vagueness concerning the nature and conceptualization of STEM

education not only among teacher educators, but also other stakeholders, including students, teachers, and policy makers (Breiner et al., 2012; Sanders, 2009; Williams, 2011). However, it is clear that one of the critical pillars for the success of integrated STEM learning environments, like any other education reform initiative (Wright, Horn, and Sanders, 1997), is the STEM teacher on whose shoulders STEM integration initiatives come to fruition (Fulton & Britton, 2011; Hutchison, 2012). In STEM education, "success is brought about by extraordinary teachers who overcome a variety of challenges that stand between vision and reality" (National Research Council, 2011, p.19). To be effective, teachers need strong content knowledge and pedagogical expertise (National Research Council, 2011; Shulman, 1986). In the case of STEM teachers, they require multidisciplinary knowledge across the STEM disciplines and a unique set of pedagogical practices that help design and implement a robust STEM integration curriculum (Kelly & Knowles, 2016; Sanders, 2009).

It is necessary for STEM teachers to understand the concepts, philosophy, and purposes that an integrated STEM approach entails (Chesky & Wolfmeyer, 2015; Breiner et al., 2012) in order to push forward the STEM experiences in their schools. Therefore, as schools move towards adapting and implementing STEM philosophy, it is necessary to decide if one teacher integrates all STEM disciplines into their classes (Hutchinson, 2012; Sanders, 2009) with all the epistemological constraints associated with each discipline (Williams, 2011; Sanders, 2009), or whether STEM teachers are disciplinary teachers, one for each subject, who collaborate in harmony, developing and implementing STEM-focused curriculum (Herschbach, 2011; Sanders, 2009; Williams, 2011). Despite this lack of clarity about STEM, STEM-focused schools are opening at an accelerating

rate (Forman et al., 2015; Slavit, Nelson, & Lesseig, 2016). With the different models of STEM, teachers are left to determine for themselves how to define: (a) STEM itself as an approach, (b) the nature of integration and (c) the role of engineering and technology, and possibly other non-STEM disciplines, in the K-12 system.

As teachers get involved in STEM integration design and practice, they engage in a process of new identity formation of being STEM teachers with the many roles and responsibilities associated with such an identity (Beijaard, Meijer, & Verloop, 2004; Cooper & Olson, 1996; Slavit et al., 2016). While there is a strong literature base related to teacher identity across disciplines and grade levels – science, mathematics, elementary, secondary (e.g. Flores & Day, 2006; Friesen, & Besley, 2013; Obenchain, Balkute, Vaughn & White, 2016) – STEM teachers' identities have yet to be included within the teacher identity literature. Therefore, research work is critical, especially regarding STEM teachers' identities and their roles in creating and enacting an instructional and curricular vision of integrated STEM. To fill this gap, this study was initiated and guided by the following research questions: (1) What do teachers identify as being important characteristics of STEM teachers? (2) How do STEM teachers identify their roles as STEM teachers?

Literature Review

STEM Education

Lofty visions and classroom practices. Real world problems are complex and inherently multidisciplinary. Tackling such problems requires not just the ability to use design thinking or inquiry, but also the ability to choose the best approach or combination of approaches that capitalizes on the strengths of each way of thinking. From this

perspective, STEM encompasses the content, skills, and ways of thinking of each of the disciplines, but it also includes an understanding of the interactions between the disciplines and the ways they support and complement each other (Moore et al., 2014). Although educators are aware of the role of STEM education as an economic imperative of education (Chesky & Wolfmeyer, 2015; Gonzalez & Kuenzi, 2012) as well as a pedagogical need to enhance learning (e.g. Lansiquot, 2016; Morrison, 2006), neither educators nor researchers consistently agree on definitions for K-12 STEM education or best practices for integrated STEM instruction (e.g. Breiner et al., 2012). However, some common ground has been found as STEM education has evolved into "a meta-discipline, an integrated effort that removes the traditional barriers between STEM subjects, and instead, focuses on innovation and the applied process of designing solutions to complex contextual problems using current tools and technologies" (Kennedy & Odell, 2014, p. 246). Unpacking this definition reveals a myriad of tasks and responsibilities for teachers. Integration in curriculum design and implementation, connecting classroom practices with the real world, and focusing on innovation and application are among the tasks that a STEM teacher is expected to fulfill (Morrison, 2006). The challenge for teachers lies in aligning such lofty definitions of STEM with their classroom practices, at times creating a dichotomy between theory and practice. Without strong STEM teachers who understand how to embody this vision of integrated STEM, STEM could be reduced to a simplistic version of "design cycles" based on hands-on activities absent of strong science and mathematical content (Williams, 2011).

Single STEM teacher or team teaching. There are two different visions/models regarding how teachers implement STEM in a school. One point of view treats the

"STEM teacher" as someone who can teach science, technology, mathematics, and engineering in spite of all the epistemological variations among these disciplines (Sanders, 2009; Williams, 2011), eventually creating what might be referred to as a standalone STEM subject or standalone STEM units within a disciplinary course. However, integrative STEM education is not intended as a new standalone subject area in the schools accompanied by new "integrative STEM education" licensure regulations (Sanders, 2009). As Sanders (2009) states:

> Given the amount of content knowledge necessary to be an effective science, mathematics, or technology educator, it's very difficult to imagine a new teaching/licensure program that would prepare individual pre- and/or in-service teachers with sufficient science, mathematics, and technology content expertise—and the pedagogical content knowledge—to teach all three bodies of knowledge effectively. (p. 21)

Among the barriers that make the alignment between the STEM vision and implementation challenging, especially in the case of the one-for-all STEM teacher, is the epistemological differences between the STEM disciplines.

Epistemological constraints. While the NGSS advocate for the integration of engineering into science classrooms, it is important to note that these fields have epistemological characteristics that differ markedly (Herschbach, 2011; Sanders, 2009). These characteristics must be fully recognized and accommodated in planning and teaching in order to preserve the intellectual integrity of each field. Otherwise, a very limited understanding undervalues specific intellectual contributions or ignores the collective value of each (Herschbach, 2011; Williams, 2011). In the following section, a

brief delineation of the epistemological differences between science and engineering as a model is explained.

Within a STEM framework, engineering is seen as an umbrella and a context for integration and therefore better learning of science and mathematics (Moore et al., 2014). Engineering can be viewed as either an applied science or as a design process. Smith (1988) defined engineering as a design process. He stated:

> [D]esign in a major sense is the essence of engineering; it begins with identification of a need and ends with a product or a system in the hands of a user. It is primarily concerned with synthesis rather than analysis which is central to engineering science. Design, above all else, distinguishes engineering from science. (p.318)

This perspective of engineering is reflected, to a large extent, in the different STEM integration frameworks used by different researchers and educators in which engineering is viewed as a real-world context for learning mathematics and science, providing a context for developing problem-solving skills, a vehicle to promote the development of communication skills and teamwork, and providing a fun and hands-on setting that will improve students' attitude toward STEM careers (Moore, et al., 2014; Roehrig, Moore, Wang & Park, 2012). Koen (2003) defines engineering as “the use of heuristics to cause the best change in a poorly understood situation within available resources” (p. 28). Heuristics are defined, in this case, as reasonable, plausible, but ultimately fallible approaches; they permit a solution or reduce the time to a solution but they do not guarantee a solution. Heuristics may include, but is not restricted to engagement strategies such as cooperative work, holistic perspective versus being lost in

minutiae, and higher teacher-student interaction (Smith, 2006).

While the goal of science is the construction of theories that can provide explanatory accounts of natural phenomena, engineering develops a systematic process for solving problems based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technological feasibility, cost, safety, aesthetics, and compliance with legal requirements. There is usually no single best solution, but rather a range of solutions (National Research Council, 2011).

Science begins with a question about a phenomenon and seeks to develop theories that can provide explanatory answers to such questions. In contrast, engineering begins with a problem, need, or desire that suggests an engineering problem that needs to be solved. Engineers use investigation both to gain data essential for specifying design criteria or parameters and to test their designs. Scientific investigations produce data that must be analyzed in order to derive meaning or explanation. Since data usually do not speak for themselves, scientists use a range of tools – including tabulation, graphical interpretation, visualization, and statistical analysis. Engineers also do the same, however, with different purposes. Engineers analyze data collected in the tests of their designs and investigations in order to compare different solutions, determine how well each one meets specific design criteria, and interpret the results (National Research Council, 2011).

Given that STEM integration is primarily promoted through reforms in science teaching and learning (Moore, 2010; Roehrig, et al., 2012), science teachers are at the forefront of most STEM initiatives. Science is, in this sense, taking the lion share of

emphasis, causing what might be called “polarity effect” of STEM integration (Roberts & Cantu, 2012). In many circumstances, STEM integrated units are strikingly leaning towards science (Herschbach, 2011; Roberts & Cantu, 2012; Williams, 2011) with little mathematics content, engineering design as a content integrator (context), and technology as a value laden tool for implementation (Kelly & Knowles, 2016).

STEM Team teaching. One way to address these epistemological considerations is to encourage a team-teaching model as an alternative to a single teacher implementing STEM. In this model, teachers work together and they are able to maintain the epistemological grounding of their discipline. Also, STEM teaching becomes more effective. Student achievement increases when teachers join forces to develop strong professional learning communities in their schools (Fulton & Britton, 2011). However, this model requires a great deal of coordination and collaboration among all teachers in both planning and implementation of STEM curriculum (Fulton & Britton, 2011; Herschbach, 2011). Similarly, Williams (2011) proposed that rather than integration, a more reasonable approach may be to develop interactions between STEM subjects by fostering cross-curricular links in a context where the integrity of each subject remains respected. This approach cannot happen in the absence of a student-centered learning environment.

Student-centered learning. While STEM models differ in some regards, there is a common thread related to student-centered learning. In existing models of effective STEM integration, the goal is to provide students with opportunities to construct new knowledge and acquire problem-solving skills through the process of designing artifacts Bybee, 2013; Morrison, 2006). This goal is accomplished through a series of open-ended,

hands-on activities related to a thematic topic that addresses important concepts related to STEM disciplines (Satchwell & Loepp, 2002). Central to this process is involving students in defining and optimizing a solution for a real-world authentic problem from students' surroundings to help facilitate a more meaningful learning process (Laboy-Rush, 2011; Satchwell & Loepp, 2002). As a result, students take ownership of their learning and have the chance to make sense of the world rather than learning isolated pieces of information (Morrison, 2006). In such an environment, teachers' roles are critical (Johnson, 2012).

Teachers' roles in a STEM setting. Within such a challenging and demanding educational environment, STEM teachers are required to adopt new approaches from the disciplinary approaches they were prepared for. STEM teachers would need to have the content knowledge and professional attributes to organize authentic STEM projects for their students (Laboy-Rush, 2011; Morrison, 2006). Accordingly, teachers need certain personal and professional traits in addition to the deep knowledge about a broad range of content areas, pedagogical skills across disciplines, and access to appropriate resources (Ruggirello & Balcerzak, 2013). In one of the few studies about the characteristics and roles of STEM teachers, Slavit, et al. (2016) described the STEM teacher as a "complex mixture of learner, risk-taker, inquirer, curriculum designer, negotiator, collaborator, and teacher" (p.7). While possessing these attributes and engaging in a new and different educational experience, teachers start to develop new identities. As such, teacher identity provides the theoretical framework for this study.

Teacher Identity

Research on teacher identity provides a comprehensive and sophisticated picture of what it means to be a teacher. Exploring the multiple influences that shape teacher identity, including, but is not restricted to, personal experiences, media images, and personal and pedagogical beliefs (Franzak, 2002). Hence, developing a teacher identity denotes an ongoing process of construction through professional life that includes social, personal, and professional experiences that happen over an extended time span (Cooper & Olson, 1996; Rogers & Scott, 2008). Watson (2006) defines teacher identity as a teacher's sense of self as a teacher, which encompasses one's personal, professional, socio-political, and cultural dimensions. Thus, teacher identity is considered a dynamic, continually changing, and active process which develops over time through interaction with different policy, school, and classroom environments and those who work in them (Schutz, Hong, & Francis, 2018). Therefore, teacher identity research takes into consideration professional, personal, academic, and social aspects, in addition to teachers' roles at schools (Beijaard et al., 2004).

Social (professional) and personal dimensions of teachers' identity. Based on reviewing research on teacher identity, there has been a clear dichotomy between looking at teacher identity either as a professional development process through an accumulation of assets, or the growing interest in the inherent personal or individual attributes in each teacher (Beauchamp & Thomas, 2009; Kelchtermans, 2005; Palmer, 1998). The first movement simply focuses on teachers' acquisition of 'assets', such as knowledge, competencies, and/or beliefs, stressing the importance of desired learning outcomes in terms of 'what is learnt' by teachers (Porter, Youngs, & Odden, 2001). This approach argues that teacher identity formation is a linear process moving from novice to expert.

However, this perspective has become debatable given large differences in how teachers develop throughout their career, both between teachers as well as between different expertise areas (Beijaard, Verloop, & Vermunt, 2000).

In addition, theories on identity development indicate that development is far from a linear process (Flores & Day, 2006). Another limitation of such an 'assets'-approach is that it perpetuates a discourse about the teacher – the teacher as being the object we look at from above or from the outside. Consequently, such an approach does not allow an understanding of how teachers themselves make sense of their teaching practice (Niessen, Widdershoven, Abma, Van der Vleuten, & Akkerman, 2008), thus opening the door for considering inherent, personal dimensions as an integral element in the identity formation process.

Akkerman and Meijer (2011) argue that there are several recurring characterizations of teacher identity. The most commonly seen characterizations are related to three main topics: (1) multiplicity of identity, (2) discontinuity of identity, and (3) the social nature of identity.

The first topic is the multiplicity of identity, which involves 'sub-identities.' A teachers' professional identity consists of sub-identities relating to teachers' different contexts and relationships.

The second topic is the discontinuity of identity as being 'an ongoing process of construction' in which teacher identity is described as fluid and shifting from moment to moment and context to context. Based on their review of literature on teachers' professional identity, Beijaard et al. (2004) stated that identity is an ongoing process of interpretation and re-interpretation of experiences. Hence, they argued that identity can

be seen as an answer to the recurrent question: “Who am I at this moment?” (p. 108). Likewise, Rodgers and Scott (2008) argued that identity is ‘shifting’ and ‘unstable’.

The third topic is the social nature of identity which relates to various social contexts and relationships in which teachers’ identity develops. Identities are formed in social, communicative contexts and for socially significant reasons (Alsup, 2006). Cohen (2010) discussed how teachers negotiate their professional identity in collaborative exchanges, concluding that colleagues constitute key actors in teachers’ formation of professional identity. In other words, Palmer (1998) stated that ‘identity is a moving intersection of the inner and outer forces that make me who I am’ (p.13). Therefore, a more holistic approach towards what it means to be a teacher emerges in which teachers’ professional identity development is understood as involving questions like ‘who am I as a teacher?’ and ‘who do I want to become?’ (Kelchtermans & Hamilton, 2004).

In this study, a teacher’s identity can be looked upon as an outcome of the dialogic relationship between personal and social interaction in a professional setting. Identity is viewed, henceforth, as simultaneously unitary and multiple, continuous and discontinuous, and individual and social. In sum, “identities are a shifting amalgam of personal biography, culture, social influence, and institutional values which may change according to a teacher’s role or circumstance” (Day, Kington, Stobart, & Sammons, 2006, p. 613). With such a view in mind, there is a movement in the identity definition and the formation of theoretical discussions from an either/or approach towards thinking in terms of a both/and approach. In other words, a teacher identity is an interaction of both personal and social dimensions as interacting in a reciprocal process of constructing and reconstructing teacher identity (Akkerman & Meijer, 2011). Specifically, this study

examines how teachers come to understand and identify themselves as STEM teachers, in the professional and personal dimensions. Specific for this study, the nature of STEM teacher identity is conceptualized by interactions between the assumed roles of the STEM teachers in their schools (e.g., Slavit et al., 2016) and the different aspects of teacher identity (e.g., Akkerman & Meijer, 2011) (see Figure 1). Personal dimension attributes represent innate or "self-image" attributes that characterize the STEM teacher's character or personality, while professional ones refer to "context" based attributes that help the teacher work in a school setting (Beijaard et al., 2004, p.113). However, at certain points, there is no clear distinction between what is personal and what is professional – there might be some overlap between some of these attributes.

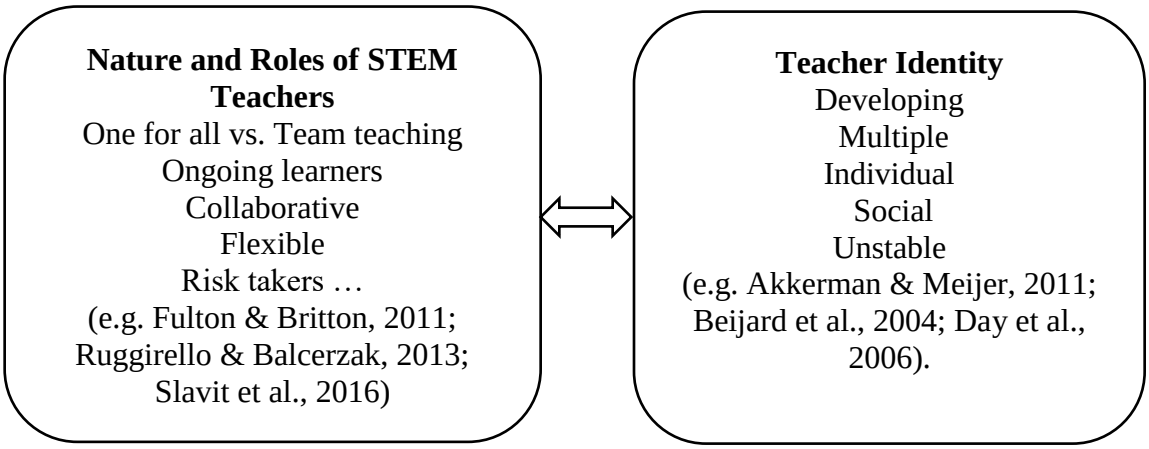

Figure 3.1. The interaction between assumed roles of STEM teachers and the aspects/attributes of teacher identity

Methodology

Research Purpose and Context

The purpose of this research was to explore STEM teachers' developing identities in two emerging, urban STEM schools in the Midwestern United States. Subsequently, this exploration can create a contextualized theory as to what constitutes STEM teacher identity (Cooper & Olson, 1996) through a grounded theory approach (Charmaz, 2014).

The two emerging STEM schools – Falconer and Noddack (pseudonyms)- were part of a larger project with five urban secondary schools in the Midwestern United States that were interested in developing a STEM focus. In each school, a STEM or STEAM ('A' for art) team was created and each school was provided with professional development support, including a STEM education graduate student who served as a classroom coach to help develop STEM curricular units and introduce STEM strategies into the schools (Crotty, Ring, Livstrom, Roehrig, 2018).

Falconer Middle School is located in a diverse working-class neighborhood. Following a series of school closures in the district, Falconer Middle School recently reopened its doors as a community school with a STEAM focus. The school hired a STEAM coordinator to work toward the goal of being a STEAM school. The student population of Falconer is 72.3 percent Black, 17.6 percent Hispanic, 1.8 percent White, 2.0 percent Asian, 3.0 percent American Indian/Alaska Native, 0.5 percent Native Hawaiian/Pacific Islander, and 2.8 percent two or more races. The percentage of the student population of Falconer Middle School that qualifies for free/reduced lunch is 87.9 percent (Minnesota Report Card, 2018). At Falconer Middle School, the STEAM team members were appointed by the assistant principal, with one team per grade level – sixth,

seventh, and eighth. Each team was expected to create and implement at least one integrated STEAM unit and have students present their work at a community STEAM night.

Noddack is a large middle school located in a historically diverse neighborhood with a highly diverse student population. The population of students who identify as White is 21.4 percent, while 40.9 percent are Black (including a large Somali population), 19.7 percent are Hispanic/Latino, 6.2 percent are Asian, 9.3 percent are American Indian/Alaskan Native, and 2.5 percent are two or more races. The percentage of students who qualify for free/reduced lunch is 76.8 percent (Minnesota Report card, 2018). Membership on the STEM team was voluntary and two teams were formed, based on teacher interest and invitations from each team leader.

The seventh grade STEM experience at Falconer was based on *Project Lead the Way*. It was led by the engineering teacher and science teacher. The sixth grade STEM experience included a unit on American-Indian history and creating dreamcatchers. The eighth grade STEM experience involved students working with local community experts (architects and designers) in redesigning a local park. Students designed and created scaled 3-D models of the park.

At Noddack, one STEM team implemented a unit about the relationships between race, culture, and genetics and how humans are more alike than different. The other STEM team developed and implemented a unit in which students raised chickens in order to learn about sustainability and growth, the scientific method, and computational mathematics for data collection and analysis.

Research Design

The study used a multiple case study design with individual teachers from the two emerging STEM schools representing the case units (Yin, 2014). Case study is an appropriate research design for this study due to its intent to explore how teachers in emerging STEM schools identify their roles in a STEM setting. As an "in depth description and analysis of a bounded system" (Merriam, 1988, p.40), this case study was delimited by the eight purposefully selected participating teachers in the two schools described above. This study provides a particularistic, descriptive, analytic, and heuristic conceptualization of the topic under investigation: how teachers see their roles as STEM teachers as well as how their identity as a STEM teacher emerges (Merriam, 1988; Yin, 2014).

Participants

Eight teachers, four from each of the two middle schools – Falconer and Noddack, described above – were the participants of this study. Participants were purposefully selected for their active participation in the STEM/STEAM team of each school. The participants provided a diverse group of teachers in terms of gender, experience, ethnic background, and age. However, they have a relatively short experience of working in a STEM setting with STEM experience ranging from two to four years. The teachers were involved in a larger project that introduced STEM curriculum in their schools and participated either voluntarily or by being selected in the STEM/STEAM team in each school. Table 3.1 shares the demographic information for the participants, the subjects they were assigned to teach, their teaching experience, age, gender, their experience in working in a STEM setting, and school affiliation.

Table 3.1

Teachers' demographics and experience in both STEM and non-STEM settings

Name*	**School***	**Subject and grade level**	**Ethnicity**	**Teaching experience**	**Teaching in a STEM setting**	**Gender**
Betty	Falconer	Science (HS) and engineering (MS)	White	14 years	4 years	Female
Gary	Falconer	7th grade Life Sciences	Asian	3 years	2 years	Male
Mary	Falconer	6th/7th/8th grade Art	Latina	28 years	3 years	Female
Nate	Falconer	8th grade Social Studies	White	13 years	2 years	Male
Calvin	Noddack	6th grade science	White	4 years	4 years	Male
Dawn	Noddack	6th/7th/8th grade Art	African-American	20 years	2 years	Male
Jay	Noddack	Social studies	White	15 years	4 years	Male
Yen	Noddack	6th/7th/8th grade science	White	13 years	2 years	Female

*Teacher's names and school names are pseudonyms

Data Collection

Interviews were conducted with the eight teachers at the end of the school year, one year into the schools' development as STEM schools. One of the authors of the study conducted all the interviews with the selected participants at their school sites. The interview questions were the following:

1. What does STEM mean to you? When you hear the word STEM, what comes to mind?
2. Do you identify yourself as a STEM teacher? Why? Why not?
3. How do your ideas about STEM align with your philosophy of teaching?
4. What do you think are important characteristics of a STEM teacher?
5. How is being a STEM teacher different from a (science/math/art/social

studies) teacher?

6. How can you see yourself as different from other teachers, if any?

Data Analysis

The interviews were recorded and transcribed. For each of the transcripts, teachers' responses to the interview questions, developed through the research questions guiding this study, were coded. Content and relational inductive open coding was conducted vertically (for each participant) and horizontally (across the different participants) (Corbin & Strauss, 2015; Miles, Huberman & Saldana, 2013). The coding was done manually and separately at first, then the authors compared their codes. Alignment of the codes was done and then an axial coding was used to identify emerging themes. Each respective interview was compared and contrasted with one another.

A cross-case comparison, with each individual teacher being considered a case, was used to synthesize the findings between the separate cases to understand similarities and differences between them (Corbin & Strauss, 2015). These final themes were then compared to previous literature related to teacher identity (Akkerman & Meijer, 2011) and the nature of STEM teachers' roles identified in literature (e.g. Slavit et al., 2016). Through this analysis, three major themes were identified: (1) nature of STEM teachers' identity, (2) professional characteristics of STEM teachers, and (3) personal characteristics of STEM teachers (Table 3.2), subsequently, creating a contextualized grounded theory of the characteristics of the developing identity of STEM teachers in emerging STEM schools (Charmaz, 2014; Corbin & Strauss, 2015; Miles et al., 2013).

Table 3.2

Themes and Codes/Subthemes Identified in the Qualitative Interviews

Themes	Codes/Subthemes
Nature of STEM Teacher Identity	Developing (emerging) STEM teacher identity Alignment between STEM conceptualization and personal philosophy
Professional characteristics	Believing in equity and inclusion Collaborative with a preference for team teaching Aware of the best practices in STEM Aware of the social issue sand community needs
Personal characteristics	Risk-taker Change agents Open to change Ongoing learning/ knowledge seekers

Findings

Three major themes emerged from the data analysis reflecting personal and professional dimensions, as well as a unique nature of STEM teacher identity. The following is a detailed description of the findings.

Nature of STEM teachers' identity

The perception of STEM across the eight participating teachers impacted their conceptions of STEM identity in a variety of ways. With the diverse background, age, gender, and subject matter, the teachers developed different conceptualizations of STEM stressing the importance of integration, as well as tackling real world problems. The alignment between these conceptualizations and their personal teaching philosophies was a critical point for most teachers; they saw that a prerequisite for success in a STEM setting is to have such an alignment. Because STEM teachers came from different subject backgrounds, their ability to identify as a STEM teacher was still unstable. Their identity is in a state of transition, causing multiple identities to form for some teachers being science and STEM, art and STEM, etc. With STEM being a new initiative in their

schools, teachers see their identity as STEM teachers as developing and under construction. However, they stressed the importance of having a degree of alignment between their understanding of STEM as a teaching and learning approach and their personal philosophy of teaching.

Teachers' conceptualization of STEM. For all interviewed teachers, STEM was about integration through the addition of engineering and application of knowledge to solve real world problems to provide an equitable learning experience for all students. As Betty stated, "STEM means to me integrated units. Adding the engineering…It has to be integrated, otherwise you have a STEM class and it's not STEM education." Jason added that it is "more real world. [It has] something about the structure [building and design]." Yen stated, "[It is] application of knowledge towards the benefit of society." Calvin maintains that STEM "support(s) students' learning" while Dawn stresses that "it is going to be inclusive…to provide equity because some kids...might not learn in the same way."

Science (as well as social studies and art) teachers who were interviewed argued that STEM provided a more inclusive and holistic learning experience. Yen said that a science teacher is closest to a STEM teacher, but conceded, "instead of being an isolated lab report, [STEM is] solving a problem [that is] very engaging. [STEM teaching] is more relevant [and] engaging, having more focus on equity and cultural relevancy. There is emphasis on the social aspects of science." Jay believed that STEM teaching "add[s] richness to the experience" of social studies teaching. Meanwhile, Mary thought that being a STEAM teacher added "a particular skill set like engineering, architecture." However, all of the interviewed teachers still think that their identity as STEM teachers is still under construction.

A developing STEM identity (STEM identity under construction). Seven out of the eight teachers described their STEM identity as still in the making. They were in process of becoming STEM teachers. For instance, Nate, after 13 years of teaching experience and 2 years of working in his present emerging STEM school, he "would identify [himself] as becoming a STEAM teacher." Mary who has been teaching for 28 years said, "I don't identify right away as a STEM teacher, but I think I'm working on it." Yen concurred, "I consider myself as an emerging STEM teacher...not yet a STEM teacher. There is a lot to learn."

Alignment of understanding of STEM and personal teaching philosophy. As experienced teachers, the interviewed teachers come to the STEM setting with their own teaching philosophies. None of them saw any discrepancies between their understanding of STEM and their teaching philosophy. For instance, Yen described a "perfect alignment" between her STEM understanding and teaching philosophy where she thought that linking learning and teaching to everyday life and "extending science experiments to the outside world, not only the lab" was essential for her work as a science teacher. Nate said, "I think being in a STEAM school is right on par with [my philosophy of teaching]**."** After serving for only four years as a science teacher in the same school, Calvin strongly argued that being a STEM teacher "centered me back to what teaching is about for me after feeling burnt out."

Professional characteristic of STEM teachers

Believing in equity and inclusion. The teachers believed that STEM provides an opportunity for engaging students in the learning process and for bridging the achievement and cultural gaps among different segments of students, including different

learning styles, interests, and potential. As stated by Nate, STEM teachers believe that "everybody wants to [and can] learn. I think that it's our job as educators to bring that out in each child." Additionally, Yen believed in role of STEM in "engagement and bridging gaps among students."

Teachers unanimously considered student learning as the focus of all the teaching/learning processes in a STEM context. Not only should teaching/learning be the focus, but mentoring as well. Yen emphasized the importance of "mentoring students in schools to get exposure to different STEM fields...while collaborating with other teachers." Jay believes that "the much more important things my students should learn is problem-solving, being okay with failing." Jay went as far as to be "happy to spend money 'to help kids' projects'." Referring to content coverage versus student learning, Yen said that "[Teachers shouldn't be] caught up in a checklist of what needs to be accomplished, but rather giving our children the space and time to inquire."

Awareness of social issues and connections between school and community. Participants believe that STEM leads to community service and solving community problems. Four teachers emphasized that teachers should be aware that they are helping the community surrounding their schools, and understand the community from all the different aspects – culturally, socially, economically, and even politically. Yen believed that "[STEM] emphasizes the social aspects of science. [STEM is] application of knowledge towards the benefit of society." Betty stated, "Teachers need to understand what [STEM] means for that community and then participate in it." Mary, who lives in the same district where most of the students come from, gave a very powerful understanding of her role. She stated, "I am [from this community] and I live here...I

want to give something to these kids that they normally wouldn't have. [I'm]…passionate about exposing them to as much as possible -- all the possibilities I have at their fingertips… It's my community; I feel responsible. I love these kids and I can't say that everybody feels the same way." Betty, on the other hand, believed in "trying to make [curriculum] more relevant for our kids or stretching it out to teach them the things they don't know."

Collaborative and a preference for team-teaching. Collaborative planning with teachers of other subjects in order to get exposure to different STEM fields was among the most recurrent themes of the teachers interviewed. "One of the main features of a STEM teacher is the ability to work with others," said Dawn. Mary emphasized that it is important to "plan with other teachers…we work as a collaborative team…integrate science into art for problem-solving purposes. So much of science is bigger than just an experiment." Calvin went as far as to state that "the best [appropriate] way…to see a STEM teacher is to be with a group of teachers. I don't think there's a stand-alone STEM teacher…[what is needed is a group of teachers with] a very mixed and diverse academic background."

Aware of STEM best practices (problem- and project-based learning). Project-based learning and problem-based learning were considered as the backbone of STEM education by the participants (e.g., Morrison, 2006; Moore, 2010). The interviewed teachers concur with this fact. According to Nate, STEM teachers work on "using best practices and [identify] what has worked before in other STEAM schools, like problem- and project- based learning which are seen as integral parts of STEM education." Betty elaborated, "I guess the part that it aligns is that it's more problem-

based. We used to call it inquiry-based [in science], but I think it's getting more specific…if we add STEM, it's going to have rigor versus if it's just inquiry-based." Yen agreed with Betty saying that, "problem-based learning is an inherent part [of] science; however, when students redesign what I do through project-based learning, they learn more as they understand what they experience more."

Personal characteristics of STEM teachers

Risk takers, change agents / open to change. One of the most critical characteristics of STEM teachers, according to the participants, is being open to change and being change agents at the same time. Betty thought that the main characteristics of a STEM teacher is the ability to be "flexible and open for change," while Jay argued that seeing failing as an opportunity for learning and "problem-solving" were critical components of a STEM teacher's character. Gary thought being "risk takers" while working in a "sustainable place to do this" is essential for the success of STEM teachers.

Ongoing learners, knowledge seekers. Teachers talked about different attributes that put the teacher in the place of the learner; they are ongoing learners, thirsty for professional development and research. Once a STEM teacher presented himself/herself as a guide and a model to his/her students, many of the characteristics needed in students had to be exemplified by the teacher. "It is a learning process," Yen said. Likewise, Jay said, "Put the teacher in the role of the learners," while Gary conceded that he is still "a student." Mary said that she has more to learn. She explained, "those kinds of things you might have to develop and learn a little bit more, but I still think that as an art[ist] and learning about the arts, you're kind of again…bringing in history or bringing in science." According to Dawn, [STEM teachers] should have the "ability to research to find the

other connections between the different forms of different technology" that would help them in their work as STEM teachers. Jay summed it up by saying "a STEM teacher should have the same characteristics a STEM student is required to have."

Discussion

Our data reveals that STEM teacher identity is not a simple construct and there are several factors at play as teachers work toward integrating STEM in their classrooms. STEM teachers described their identity development as a journey of ongoing learning, collaboration, awareness of the community needs, and alignment of their own teaching philosophy with the requirements of a STEM approach. These conceptualizations concur with the reviewed literature on teacher identity (e.g., Akkerman & Meijer, 2011; Franzak, 2002; Schutz, et al., 2018) where the nature of teacher identity is viewed as a dialogical concept where personal and professional experiences interact to create an emerging STEM teacher identity in the context of this study.

Both at the personal and professional levels, teachers interviewed in this study provided a clear picture of how they see themselves as STEM teachers in a developing STEM setting. Viewing themselves as emerging or developing STEM teachers fits within the conceptual underpinnings of teachers' identity (e.g. Akkerman & Meijer, 2011; Mockler, 2011; Watson, 2006) per the ongoing process of identity building through different contexts and experiences. Teachers present what can be described as a "fluid identity," where the new STEM experiences they are involved in through professional learning and creating integrated STEM experiences for their students adds a new dimension to their existing teacher identity. While these new STEM experiences create a higher level of commitment and motivation for the teachers to go through the new

journey of identity formation, they, in turn, explain how experienced teachers serving more than twenty years of teaching see themselves as developing STEM teachers. This aspect concurs with the argument of Rodgers and Scott (2008) that states that identity is 'shifting' and 'unstable'. Day and colleagues (2006), concomitantly note that "identities are a shifting amalgam of personal biography, culture, social influence, and institutional values which may change according to one's role or circumstance" (p. 613). This is exemplified by what the participants had to say in the interviews; Mary, for instance, mentioned she was "working on it [developing her identity as a STEM teacher]."

Viewing the educational experience through wider lenses is another aspect of the emerging identity of the teachers in these emerging schools. STEM is seen as providing a wider perspective than individual disciplines such as science, social studies, and art. The teachers see themselves as providers of a more holistic learning experience to their students. For instance, though Yen referred to herself as a science teacher, she instantly conceded that STEM is more comprehensive and "more relevant and engaging" if compared to the science silo where the teacher is "isolated in the science lab."

As identity formation is viewed as an outcome of the interaction of what is personal/individual and what is professional/social (Akkerman & Meijer, 2011; Day et al., 2006), participating teachers stressed the need for an alignment between what they personally believe as a teacher and the philosophy of integrated STEM education. This alignment between what is personal and what is professional/social provides another layer of teacher identity that could provide answers to questions such as, "Who am I as a [STEM] teacher now?" and "What do I want to become?" (Kelchtermans & Hamilton, 2004). There was a unanimous emphasis among all teachers interviewed on the necessity

of such an alignment. The interviewed teachers denote on different occasions in their responses that there is an alignment between their personal teaching philosophy and their conceptualization of STEM. For instance, Yen described this alignment as “perfect”, while Nate stated that a STEM approach is “right on par with [his philosophy of teaching].” Inversely, when a teacher’s philosophy is unaligned with the STEM requirements of ongoing learning and inclusive teaching, there would be a problem. This misalignment would not only adversely affect the professional community, but it would also cause problems for both students’ learning and eventually to himself/herself as an educator.

The job of a STEM teacher is challenging given the wide range of requirements at different levels, including curriculum design, implementation, being aware of the best practices in the field, and having an eye on social issues. (Morrison, 2006; Hutchison, 2012; Ruggirello & Balcerzak, 2013; Slavit et al., 2016). This scope necessitates that STEM teachers, from the perspective of our participants, possess certain characteristics, including being an ongoing learner, being open to change, looking at failure as an opportunity for learning, and believing in the need to provide equitable and inclusive learning opportunities to all students. Given the growing need for STEM teachers for the advancement of STEM programs all over the country and the world (National Research Council, 2011), understanding the critical characteristics of STEM teachers is an important part of advancing to that goal.

Teachers emphasized the need for collaborative work in a sustained manner in order to help build equitable and inclusive learning experiences for students. They see collaboration, mainly in the team-teaching model, as vital for the success of a STEM

teacher. The need for integration and interaction of different disciplines to solve problems is a basic feature of STEM education (e.g. Bybee, 2013; Herschbach, 2011; Moore, 2010). If a teacher is not collaborative or is reluctant to engage in ongoing professional learning to develop his/her teaching skills, he/she will probably be a big hurdle for the STEM team that requires higher levels of collaboration and ongoing learning (Wang, Moore, Roehrig, & Park, 2011). Not only does teacher collaboration support student learning, teachers who work in strong learning communities are more satisfied with their careers and are more likely to remain in teaching long enough to become accomplished educators (Fulton & Britton, 2011). Therefore, developing a collaborative professional atmosphere in a STEM setting is one of the prerequisites for a successful STEM integration (e.g. Fairweather, 2008). This integration is usually done in a framework of flexibility and openness for change. Betty, for instance, thought that the main characteristics of a STEM teacher was the ability to be "flexible and open for change", while Calvin and Dawn believed that a huge feature of a STEM teacher was "being capable of communicating with colleagues" (Hutchison, 2012; Ruggirello & Balcerzak, 2013; Slavit et al., 2016).

Conclusion

In this study, we explored the developing identity of STEM teachers in emerging STEM schools. Teacher identity, as explored in this study, reflects a dynamic nature; it is developing and changing in nature. Teachers see themselves as learners, still on the road to becoming full STEM teachers, equipped with different dispositions on the personal and professional level. Developing a STEM teacher identity can be viewed as marathon not a sprint.

In the words of one of the STEM teachers, “a STEM teacher should have the same characteristics a STEM student is required to have.” This statement is true at all levels – personal and professional. STEM teachers need to be flexible, open to change, collaborative, problem solvers, and aware of the recent trends in teaching and learning. In addition, STEM teachers have a teaching philosophy aligned with their understanding of STEM education. This alignment reduces the internal conflict between what a teacher believes and what he/she is required to do in addition to decreasing the external conflict with other stakeholders while grappling with the process of implementing a STEM focus.

Implications

This research contributes to the literature of STEM teacher identity and better understanding of the changing roles of teachers in a STEM school. Understanding the necessary characteristics of STEM teachers informs decision making for teacher preparation, recruitment, and selection to work in STEM schools. This understanding, in essence, would help promote teacher performance leading to higher levels of student achievement while reducing internal and external conflict for teachers working in a STEM school (Fulton & Britton, 2011; Slavit et al., 2016; Wang et al., 2011). We must keep in mind the high demand for well-prepared STEM teachers (National Research Council, 2011) and the need for teachers who can align their personal teaching philosophies to STEM requirements, who behave with a learner mindset, who are problem solvers, and who are collaborators.

People in leadership roles in STEM schools can benefit from the results of this study at different levels. First, they need to believe genuinely in the ability of STEM to make changes in students’ learning, and not an opportunity for a catchy title or funding.

Second, in terms of teacher selection, clear criteria for selection where the different characteristics of STEM teachers discussed in this paper, such as alignment of personal teaching philosophy and requirements of STEM, flexibility, and openness for collaboration, are rigorously utilized. These criteria can be established by using structured interviews and/or class observations in the early stages of recruitment. Third, while implementing STEM curriculum in the school, school leaders should show the needed support in terms of an understanding of what it takes to implement STEM curriculum, provide the necessary guidance, and timely professional development programs within a collaborative professional learning community. In brief, a STEM school principal should have the same or similar characteristics to be found in STEM teachers and/or students. A STEM school principal "can very well be the provocateur, the [one who] leverage[s], the agent of change, and the one who opens the door, inviting and supporting new thinking and new practice into his or her school" (Myers & Berkowicz, 2015, p. 31).

Future Research

This study was based on interviews with teachers working in emerging STEM schools regarding their assumptions and conceptions of the roles and identity formation as STEM teachers. More research is needed in order to understand if and how these reported characteristics of a STEM teacher corresponds to actions in their classrooms, and the impact of these conceptions on students' interest and learning in STEM disciplines. Also, more work is needed in order to explore the discrepancy between existing teacher preparation programs and STEM requirements. Six out of the eight teachers indicated that teacher preparation was not preparing qualified STEM teachers

who can implement the required teaching and learning strategies, and above all, have the personal and professional characteristics to be STEM teachers. More emphasis on integrated approach in teacher preparation courses that encompass some engineering background is needed to address this shortage.

Chapter 4
Gender Equity in STEM Education: The Case of Egyptian STEM Girls: An Intrinsic Case Study

Introduction

Gender equity in education, especially in science, technology, engineering, and mathematics (STEM) education, is a global priority (Penner, 2015). For example, only 20% of bachelor's degrees in the United States were awarded to women in physics and engineering, with only 35% of degrees across all STEM fields being awarded to women (Hill, Corbett, & Rose, 2010). Women's under-representation in STEM has been observed in 50 countries around the world, making it a global issue present in both post-industrial and developing countries (Sikora & Pokropek, 2012). Research in this area has explored underlying reasons behind the gender gap in STEM fields through consideration of biological, social, cognitive aspects or career preference and initiatives designed to promote females' pursuit of STEM (Ahlqvist, London & Rosenthal, 2013; Baker, Krause, Yasar, Roberts & Robinson, 2007; Hill et al., 2010).

Most of the research in gender equity in STEM education has been conducted in the Western world. Whereas, in the Arab world, gender equity is primarily reported by international organizations such as the World Bank (e.g., World Bank, 2012) from a developmental perspective. Gender equity in the Arab world – a diverse grouping of 22 countries in the Middle East and North Africa – ranks lowest in the world (World Economic Forum, 2018). Arab countries have the lowest female employment rates in the world. The few women in male-dominated fields experience traditional gender dynamics, are promoted less, and have little access to decision-making positions (Abirafeh, 2017).

Assaad and Krafft (2015) argue that the roots of the gender disparity in the Arab World are 1) the patriarchal structure in the region, 2) dominant public sector employment and weak private sector employment, and 3) an inhospitable business environment for women because of the conservative nature of gender roles. Within the Egyptian context, women have not exceeded 24.2% of the overall workforce and are even lower in the male-dominated field of engineering (Central Agency of Public Mobility and Statistics (CAPMAS), 2017; Krafft & Asaad, 2015). Attempts to address this have been underway since 1990s, including the establishment of STEM schools which provide the context for this study.

Two public STEM high schools (one for boys in 2011 and one for girls in 2012) were established to provide an alternative to the existing traditional teaching and learning approaches in Egyptian education system (Rissmann-Joyce & El Nagdi, 2013). This was considered a bold move towards ensuring equitable STEM education opportunities for both male and female students (Abouserie & Merlino, 2014). All graduates from the first STEM school cohorts have joined STEM tracks in higher education institutions inside and outside Egypt. These STEM schools have unleashed the STEM potential in Egyptian young people, male and female (Abouserie & Merlino, 2014; Rissmann-Joyce & El Nagdi, 2013), and thus warrant exploration into their success in motivating Egyptian females into STEM careers. Hence, this study was initiated and guided by the following research questions:

1. What were the experiences, successes, and challenges of the female graduates of the Egyptian STEM high school that motivated them to pursue STEM fields in higher education?

2. What were the underlying social, personal, and school factors that made these STEM experiences successful?

Literature Review

Egypt and gender inequity in education

The Egyptian General Secondary Education (EGSE) Certificate is the official gatekeeper for higher education in Egypt. The percentage of girls passing the EGSE exams in 2016 was 92.3 % compared to 87.8% for boys and in 2017 87.7 % for girls and 84.0 % for boys (Egypt Ministry of Education, 2018). Yet female numbers in science and engineering in higher education do not reflect these scores. Further, a comparison between females joining engineering schools and those who take up engineering professions reveals a further gap between academic study and employment (CAPMAS, 2017). The share of women within professional and scientific fields in Egypt is among the lowest in the world (Schmuck, 2017).

Family background, and geographic differences all contribute significantly to these gender disparities (Krafft & Assaad, 2015) in a country where women are seen as fragile and unable to compete with men in jobs like engineering. Culturally, this type of work is seen as taking a woman away from family which is considered the appropriate role for women (Krafft & Assaad, 2015), inevitably reinforcing the institution of marriage as a permanent alternative to work (Verme, Barry, Guennouni, 2016), especially when husband has the financial ability to sustain the household.

Research perspectives on Gender gap in STEM

Different perspectives have emerged as to what constitutes barriers to women in the STEM fields (e.g., Ahlqvist, London & Rosenthal, 2013; Clewell & Campbell, 2002;

Little & León de la Barra, 2009; Penner, 2015). In the following section, these perspectives are reviewed.

Different inherent interests. Some researchers argue that girls' and boys' interests are inherently different (Little & León de la Barra, 2009); girls are more interested in issues to do with human health and well-being, whereas boys are more interested in things to do with technology and physics (Penner, 2015). Even within science, it has been reiterated that women with an interest in science are more likely to enter fields such as psychology and the biological sciences. Indeed, interest in physical science on the part of boys and biological and social sciences on the part of girls has been found in children as early as first grade (Clewell & Campbell, 2002).

Cognitive differences. There is conflicting evidence regarding gender differences and academic performance in STEM. A meta-analysis of 100 studies found that gender differences in mathematics performance are small (Hyde, Fennema, & Lamon, 1990), while Mau and Lynn (2001) reported that males scored significantly higher on college entrance exams in the United States, yet females obtained significantly higher grades while in college. Belenky, Clinchy, Goldberger & Tarule (1997) posited that women come to know things in ways different from those of men; men tend to consider facts in isolation, while women integrate them into a broader context. Thus, traditional mathematics teaching that targets algorithms and emphasizes abstraction, logic, and certainty may impact females' achievement in mathematics. Belenky et al. (1997) also concluded that even the women who were extraordinarily adept at abstract reasoning preferred to start from personal experience (Häussler & Hoffman, 2002). Thus, girls are expected to perform better in mathematics if teaching builds on the strengths of

connected learners, focusing on experience, conjecture, induction, creativity, and context (Belenky et al., 1997).

Socio-cultural aspects. Socioeconomic and cultural elements also play a major role in determining female students' attraction to STEM related fields (Penner, 2015; Hill et al., 2010; Schellinger, Billington, Britsch, Santiago, Carter, & Hughes, 2018). The dominating social and economic culture, as well parental influence, that can be overt or subtle, may have a great effect on female students' academic preferences (Verme et al., 2016). Hill et al (2010) presented eight key findings that point to environmental and social barriers to female interest and pursuit of STEM fields— chief among them are stereotypes, gender bias, and the climate of STEM departments in colleges and universities — that continue to block women's progress in STEM.

Stereotype threats are considered a major factor contributing to gender disparity in STEM (Nosek et al., 2009). Steele (1998) explains that a stereotype threat "refers to the experience of being in a situation where one recognizes that a negative stereotype about one's group is applicable to oneself" (p. 5). Stereotype threats include the belief held by many pre-college women that they would be isolated in engineering tracks due to their gender and that they do not have a strong enough mathematical background to pursue an engineering career (Nosek et al., 2009). Nosek et al (2009) argue that stereotypes predict national gender differences in science and mathematics achievement, rather than simply a consequence of generalized national gender inequality. Schellinger et al (2018) stress the need for building a positive learning environment to enable female students to develop positive STEM identities that persist across K-16 and into STEM careers and dispel stereotype threats.

Pathways to improve gender equity

Confronting gender disparities in STEM requires efforts on several fronts: socio-cultural, personal, and school levels including fostering self-efficacy and improving the classroom environment to create a female friendly atmosphere to overcome stereotype threats. At the school level, teachers need to change the way they give critical feedback; foster intergroup conversations among students from different backgrounds; allow students, to affirm their most valued self; help students develop a narrative about the setting that explains their frustration while projecting positive engagement and success to improve their sense of belonging and achievement (Steele, 2010). In this sense, calls for girl-friendly instructional strategies are timely (Dare, 2015). These strategies include making content relatable to everyday applications through societal connections and connections to prior experiences (Häussler & Hoffman, 2002). Girls' participation in hands-on activities and participating in extra curricula STEM activities has been shown to enhance girls' skills (Baker, 2013; Little & León de la Barra, 2009).

Self- efficacy. Fostering girls' self-efficacy is a significant factor in improving equity in STEM (Heilbronner, 2011, 2013). Self-efficacy refers to one's belief about their ability to succeed in a certain task (Bandura, 1977). Increasing self-efficacy can overcome the stigmatized stereotypes of women being perceived as not compatible for STEM fields (Ahlqvist et al., 2013; Nosek et al., 2009). Integrating STEM project-based learning into the curriculum and providing female role models can enhance STEM self-efficacy and professional commitment to engineering (Liu, Lou, & Shih, 2014).

Same gender learning environments. Riegle-Crumb et al. (2006) reported that the academic performance of friends of the same gender significantly predicted course

taking in all subjects for girls. Specific to mathematics and science, “the effects of friends' performance are greater in the context of a predominantly female friendship group, which suggests that such groups provide a counterpoint to the gendered stereotypes and identities of those subjects” (Riegle-Crumb et al., 2006, p.221). The creation of same sex learning environments is also responsive to what the American Association for University Women (AAUW) (2000) refer to as indicators for gender bias in co-educational classrooms, both at the K-12 and higher education levels. AAUW (2000) maintains that females have historically received less teacher attention than boys, feel less comfortable speaking out in class, face threats of sexual harassment in school. These indicators suggest single-sex schools or classrooms as a solution to the gender gap in STEM. The National Association for Single Sex Public Education (NASSPE) also indicates that girls in single-sex educational settings are more likely to take STEM classes as girls have more freedom to explore their own interests and abilities in single-gender classrooms.

However, there are conflicting findings concerning single sex educational experiences (Datnow & Hubbard, 2002) that warrant further research. Both single sex and coeducational schooling can provide successes or failures depending on how these school systems are implemented, indeed “sex- segregated education can be used for emancipation or oppression. As a method, it does not guarantee an outcome.” (Kruse, 1996 p. 189). In other words, the quality of the education provided in terms of professional well-trained teachers; well-equipped schools, and well- designed, engaging curriculum; and positive school atmosphere is the main factor for success in either system.

Based on the literature reviewed, it can be argued that girls are able to excel in STEM related fields when they are placed in a learning friendly atmosphere, where quality education is provided and social barriers such as stereotyping and gender bias are absent. Providing female friendly school environments, using dynamic formative assessments, STEM focused curriculum (Peters-Burton, Lynch, Behrend, & Means, 2014), working in a non-competitive, and in some cases same sex environment (Datnow & Hubbard, 2002; Kruse, 1996) can be assets towards improved girls' performance, excellence and understanding of STEM related fields.

Conceptual framework

Socio-cultural critical stance

In this study, understanding the socio-cultural nature of gender inequity in STEM emanates from a social critical theory framework, where the commitment to justice liberates individuals from conscious and unconscious constraints that interfere with balanced participation in social interaction (Collins, 2004, 2015). This critical theoretical approach aims to analyze the constituents of the cultured context and replace them with emancipatory ideologies. One of the basic assumptions of critical theory is that knowledge generation can be based on a critical reflection of the power relationships which are embedded in the structures and functions of society where society is structured by meanings, rules, convictions or habits adhered to by social beings (Collins, 2004; Crenshaw, 1991).

In spite of all the written documents, laws and codes of ethics that guarantee equity in all fields, the low representation of females in different male dominated fields might underlie, in addition the social intersectional power dynamics, the less-than democratic character of STEM occupations (Slaton, 2015). There is compelling evidence

that gender roles are largely created and maintained in structured social order, with specific roles assigned to each group that reflect a myriad of cultural, social, religious, and political beliefs and boundaries (Davies, 2003; Kumashiro, 2002). Davies (2003) alluded to the subtle perception disseminated among family members and society at large that girls are looked upon as "fragile, weak, and powerless" (Davies, 2003, p.68), making a decision to pursue engineering as a career is a challenge to this social image. "Resisting this prevailing pattern gender inequity, occurs on three levels: personal level; the group or community level of the cultural context created by race, class, and gender; and the systemic level of social institutions" (Collins, 2004, p. 227).

Methodology

Context of the Study

The STEM High School for girls in Cairo, Egypt, along with another school for boys were the first two model STEM schools in the country The girls' STEM school was established during the turmoil and rising aspirations of January 25th, 2011 revolution. The STEM initiative in Egypt was supported by a grant from the United States Agency for International Development (USAID), with Education Consortium for the Advancement of STEM in Egypt (ECASE) leading the process of curriculum development, teacher professional development and technical support (Abouserie & Merlino, 2014). The number of STEM schools has now expanded to 11, located in different Egyptian Governorates with hopes of having a school in each of the 27 Governorates.

Both of the first two STEM high schools were boarding schools, with students being selected from across the country according to merit-based criteria. Teachers were selected mainly from the existing teachers in the Ministry of Education through a

competitive process that included an online language exam, subject matter test, and interview with Ministry of Education officials (Abouserie & Merlino, 2014; Rissmann-Joyce & El Nagdi 2013). The language of instruction is English, while most of the students come from schools where Arabic was the language of instruction.

Students in the girls' STEM school experienced the same curriculum as the boys' school, including project based learning. The female graduates have been successful in terms of enrollment and achievement in the STEM fields. All the graduates of the first two cohorts – except for two who joined business administration - joined STEM tracks in higher education institutions. Around 70 % joined science and engineering programs at universities inside and outside of Egypt. The other 30 % joined medical sector schools like school of medicine, pharmacy, and physiotherapy. Students participated and won prizes in science and engineering fairs on the local and international levels, encouraging more girls to follow on their footsteps, as evidenced by the large numbers of girls competing to join these schools and the number of girls applying for STEM schools outnumbering boys in 2017 (USAID, n.d.).

Researcher positionality

The first author started working at the STEM school for girls in the second semester of its first year as a teacher of English as a foreign language. Subsequently, he took over the role of the professional development for the teachers and supervising the students' capstone STEM projects completed each semester. This provided a rich understanding of the school context and familiarity for the participants in sharing their experiences.

Intrinsic Case Study design

An exploratory, descriptive intrinsic single case study design (Stake, 1995) was used in this research. In this case study, the individual participants represent the units of analysis. An intrinsic case study is an appropriate design for this study as the purpose of the research was to look at the experiences of the STEM girls in its entirety including social, school, and personal aspects. The study was reflective and retrospective nature as the participants graduated from the school three years ago. This provided a robust design as the participants had a chance to reflect on the impact of their experiences at the STEM school on their learning at the university level.

Participants

Participants (see Table 4.1) were purposefully selected utilizing a criterion sampling technique (Yin, 2014). The criteria used for selection were (1) female graduates of the STEM school who joined engineering schools in higher education, (2) lived in the United States at the time of the study, (3) came from different geographical locations in Egypt to reflect the different socio-cultural background of different locations in the country, and (4) from the first cohort of girls at the STEM high school. Selecting students living in the United States was a delimitation as a response to logistics reasons. Five graduates who pursued engineering at higher education in the United States were selected.

Table 4.1

The participants' names, geographical locations, family background and HE majors

Name*	Where from	Parents' background	HE major
Aida	Cairo	Father is an engineering professor and mother is in management position.	Computer Engineering
Alia	Cairo	Father is an engineer.	Biomedical Engineering
Fareeda	Delta	Father passed away while at elementary student and mother is a teacher and brother is an engineer.	Chemical Engineering
Latifa	Delta	Father is a civil servant and mother is a language teacher.	Computer Engineering
Muneera	Upper Egypt	Both father and mother are high school education level and all her siblings are medical school graduates or students.	Biomedical Engineering

*Names are pseudonyms.

Data Collection

Semi-structured interviews were conducted with the five participants. One of the interviews was done face to face, while the other four interviews were conducted using Skype. Interview questions were designed to inform the research questions and address the different aspects of the conceptual framework of the study (see Table 4.2).

Table 4.2

Sample interview questions aligned with research questions

RQ	Sample Interview Questions
What experiences, successes, and challenges did the graduates of the Egyptian STEM high school have that motivated them pursue STEM fields in higher education?	How would you describe your experience at the STEM school? How was working with girls from different backgrounds for you? What was it like? What was special about the school's curriculum? Describe how were teachers' teaching approaches different? How was assessment different from those in your previous school, if at all?
What were the underlying personal, social, and school components that made these STEM experiences successful?	Tell me a little about your family? What is your father's occupation? Your mother's? What were your major interests before joining STEM school, literature, mathematics, science? If the MoE decided to build more STEM schools, what would they consider? Tell me a little bit about how you thought about mathematics and science in middle school?

Data Analysis

The interviews were recorded, transcribed, and coded. Content and relational inductive open coding was conducted vertically (for each participant) and horizontally (across the different participants) (Corbin & Strauss, 2015). Next, axial coding was used to identify emerging themes. The data were revisited multiple times to make sure that the emerging themes and subsequent assertions were backed by the participants' words and perspectives.

An in-depth data analysis was used to synthesize the findings between the separate cases to understand similarities and differences among them (Corbin & Strauss, 2015). These final themes were then connected to the framework of the pertinent research on gender equity in STEM (e.g. Baker, et al., 2007; Hill et al., 2010; Rosser, 1993; Schellinger, et al., 2018). Ultimately, a contextualized grounded theory depicting a

layered pattern of supports and barriers for equity in STEM education in this case emerged.

Findings

In this section, individual case narratives provide an overview of the participants' unique experiences. Next, the themes that emerged from the cross-case analysis are shared. In the discussion section, these findings are discussed and expounded upon, providing an intersectional pattern of supports and barriers to gender (in)equity in STEM education in the study's context.

Individual cases

Fareeda

Socio-cultural background and family biases versus personal choices. Fareeda's family members, mother and brother, who is an engineer, and teachers in the primary and middle school, who were overwhelmingly female, adopted the perspective that "engineering is not for a girl." Fareeda faced huge opposition to her desire to be an engineer. Her brother told her that "engineering is hard for me as a boy; what about you as a girl?" Additionally, Fareeda's late father was hoping that she would be a doctor one day, so in addition to her living family members' preferences she also wanted to honor her late father's wishes.

This bias was confronted by high degrees of self-efficacy, resistance, and persistence. Fareeda insisted, now "I see myself as an engineer and I will be an engineer." However, while at the STEM school, she decided to join the science major as this was the path to medical school in the Egyptian system, whereas entry into engineering would have required her to major in mathematics in high school. Her EGSE scores qualified her

to join the school of medicine, however, she told her mother and brother while she realized their dreams, but she wanted to pursue her own dreams and instead applied for an engineering school in the United States, where she was accepted with a scholarship. She recalled, “They did not object this time. And my brother started to support me in my new adventure.”

STEM experience: successes and challenges. Fareeda valued her experiences at the STEM school. The teachers, in her view, were “like our parents” and “they were caring for us and tried to help us the most. When I talked to the physics teacher about my dream to be an engineer while my family wanted me to be a doctor, he told me ‘follow your dream as you won’t excel in a thing you don’t like.”

Fareeda saw the curriculum as challenging, describing it as “so hard with material from college.” While the college level material and rigorous assessment were challenging, Fareeda shared the benefits of being prepared for university level coursework. For example, the level of rigor was such that she “skipped chemistry 1 and 2, and physics 1 and 2 at college.” The shift from learning science and mathematics in Arabic in her previous school to English in high school, added difficulty to the already challenging curriculum. Fareeda stated “language was one of the biggest challenges we had in the first year… but the language course we had was so effective.” Assessment was also “different and difficult” with a “final exam each semester which accounted for 30 % of the final grade where we worked collaboratively to solve one of the grand challenges of Egypt following the engineering design process.” This was completely different from the mainstream secondary schools where grades were based solely based on traditional final exams. She was concerned that “the teachers needed more training and professional

support in STEM," especially with regard to assessment as "we were, not trained enough to answer the kind of questions we faced in the final exams."

Extra- curricular work. Fareeda viewed engaging in different out-of-school activities and field trips as one of the greatest assets of the STEM school. Fareeda described the International Science and Engineering Fair (ISEF) experience as the "best thing that happened" to her in the STEM school. She learned a lot from that experience, in addition to winning the first award and participating in the United States international competition and winning the third place in their category, she learned "group work, presentation skills," and how to defend her ideas "in front of Nobel laureates."

Single sex schools. Fareeda was a staunch supporter for single sex STEM schools as long as "they provide quality education and have similar teachers [to our school] and [similar school] environment." She argued that the female students "felt more comfortable" and had "the chance to work together freely without pressures, to compete in the female way to excel." She concluded, "it was a great experience all over. We worked together in a friendly way."

Aida

Socio-cultural and family biases versus personal choices. Aida's parents were supportive of her choices. Aida's father, who received his PhD from the United States and is now an engineering professor, and her mother, who holds a managing position in a big company, "encouraged [her] and said let her try and discover on her own." Prior to attending the STEM School, Aida attended a language school where mathematics and science were taught in English, which was an asset in the STEM school where instruction was all in English. However, she was more interested in "sports." Later, she discovered

that she was good at mathematics; “I do calculations fast, and understood mathematical problems, but I did not imagine spending my life doing that [dying mathematics].” She became interested in “education and engineering’ only after witnessing the January 25th revolution and understanding how Egypt needs more educated people, scientists, and engineers to change its status quo. Aida believed that her study and career choice was not only affecting herself, rather “education especially engineering will help improve our country in the future” and that as an engineer she would “have a bigger impact than just like being a politician, architect, or doctor.”

STEM Experience: successes and challenges. Aida stated the school changed her view about education as not just “buildings where students go to learn more math and science” that that education is “about changing our way of thinking.” Aida described the teachers as “very friendly even at the moments we made sit-ins and called for reforms to make our school better, they backed us.” She went on to say, “They escorted us in our journeys outside the school looking for materials for our projects, and meeting with other experts in different places.” She added, “they helped us to find different new ways to get new information, they used different teaching approaches like discussion.” Teachers were careful to warn students that “being different [as STEM students] does not mean being better than anyone else we're all good in our own unique ways.”

Aida also highlighted the rigorous curriculum stating, “the curriculum was so challenging with college level material”. Aida described the different modes of assessment used at school as very conducive to learning. For the capstone, for instance, she mentioned that “each group was required to submit the following: a prototype or model of their solution, a scientific poster of the whole project, the project portfolio, and

do biweekly journal reflections." As a result of the challenging curriculum and assessment, Aida "had an idea about nearly all the topics in my freshman year in classes like physics and calculus." Also, through her experience with girls coming from "different parts of Egypt with different cultural backgrounds", Aida gained a lot of experience with dealing with people from different backgrounds which was "very helpful for her life in college in the United States."

Extra-curricular work. The research work required of students at the STEM school pushed them to seek support outside the school walls. Aida recounted, "when I was in school, I worked on a project with the physics department at the American University [in Cairo]. I also went to Cairo University, and different [other] universities for school [projects] that helped me understand how research is done in university." Aida thought that these activities were of great value in her college level studies.

Single sex schools. Aida thought that single sex schools are "good, but they need more planning." If she were to choose between a co-ed or a single sex school, she would "choose a single sex school because the friendly atmosphere developed at the school made the students closer to each other in a way you can't find in another school."

Alia

Socio-cultural biases versus personal choices. Alia's father, being an engineer himself, "pushed her forward." She stated, "my parents were really encouraging and whenever I was in doubt, they would tell me it's a great opportunity and I should continue and work harder. They were pretty supportive. I don't think they had any negative feelings towards STEM school at all." Her favorite subjects were mathematics and science which "were not challenging for me at all, what was challenging was the

memorization-based subject like Arabic and social studies." She selected the STEM school as "the news spread about this school that it will be project-based learning and not memorizing. stuff like that."

STEM experience: successes and challenges. Alia considered her STEM experience as "a very good one that I am grateful for being part of it." She expounded on that by pointing out how the STEM school experience made them "independent [learners] in terms of that we had to self-learn, think, collaborate, and create … and come to class prepared to present." In her opinion, this was "interesting as it was student centered and taught us teamwork." She mentioned the capstone project as "pretty challenging but also very useful in terms of helping us to acquire more knowledge, research skills, such as problem solving and technical skills like for creating the prototype, not to mention enhancing presentation skills."

Alia thought "the curriculum was very different from regular schools in Egypt and challenging." She also noted that the "assessments were different from the ones they had been used to, but we could eventually answer most of the questions." Alia found the college level material very helpful and shared that when she went to college, she "found many things especially physics and math I had covered in STEM school… and the way was taught it was special" because it helped her to be an independent learner and know how to collaborate. On a personal level, she felt "it [STEM school experience] made me more confident and made my first years at college easier."

Extra-curricular work. Alia mentioned visits to "different universities and research centers and talking to professors about their projects" as reinforcing their STEM identity as they were "able to ask questions and discuss our work in a free way." Alia

described the physical work they used to do build their projects prototypes; “in addition to engineers and professors who helped us in designing our [capstone projects] prototypes, we also sought the help of technicians like plumbers, carpenters, electricians to build certain parts of these prototypes.”

Single sex schools. Although Alia initially stated that she “did not have a preference” for single sex vs. co-ed schools, she “would choose the single sex school just because we created a community in which we lived together as sisters, it was kind of empowering.” Therefore, if she were given the choice, she “would definitely go for single sex schools.”

Latifa

Socio-cultural and family biases versus personal choices. Latifa, whose father was a civil servant and mother a teacher of Arabic, used to dream of being a doctor. Her mother thought “engineering is more like for the guys, but medicine is very good for girls.” Before she joined STEM school, Latifa was interested in mathematics which “has always been my favorite subject at school, even before STEM school, because for me it was very easy to do, like it's just simple, but I didn’t like social studies because it needed a lot of memorization.” While at the STEM school, she realized that as she was “better at math[ematics], it only makes sense if I become an engineer.” When she decided to major in mathematics in high school as the pathway to engineering, her mother was initially upset. However, she did not press Latifa since she trusted her choices; “my mother believed in me.” Later, her parents became “so proud of” her and started to look at her as “an idol [model] for other students to follow.” Interestingly, this did not prevent Latifa’s

mother from occasionally reiterating her wish that her daughter had chosen “the biology major and then she can become a doctor.”

STEM experience: success and challenges. Latifa considered her STEM experience as “the greatest thing that happened and will ever happen in my life and I'm not exaggerating.” It helped her to become “a good learner and a researcher.” She stressed the perspective that the things she learned in STEM school would not have been possible in any other place: “I learned teamwork…how to talk with different people who have different perspectives and everything literally everything …all that I learned in STEM school way practice and [with] teachers’ guidance.” Her teachers used different teaching approaches: “some let us prepare materials and present them and they gave us comments and guided our discussions.”

Latifa thought that what made the curriculum different was the idea of not being restricted to text books; “you can understand the learning outcome from different references: the internet, teachers, colleagues.” In addition, in her view, the capstone projects were “the biggest point of the learning in STEM I guess… how we were supposed to deal with real-world problems and like find practical solutions for them. That was big.” This was initially challenging for Latifa as she was not used to this approach to learning and also that the teachers were learning this new system alongside the students - “if teachers do not know or do not understand the [STEM] system, that would be a big problem for students because if students don't understand what the system is, teachers should know because they're supposed to teach students how to do things.”

Because of the college level content at the STEM school, Latifa “tested out of calculus 1, 2, and 3 [because] most of these topics I covered in high school and also like

physics one and two and chemistry one. I had all these topics [covered] in high school. Now I'm in physics 3 and I study some topics about waves and resonance and I remember how I used to watch videos explaining these topics in high school**."** She added that other things like "presentation skills and collaborative work [she learned at STEM school] were very helpful at college level."

Extra-curricular work. Learning, for Latifa, did not happen only inside the school. Latifa described her participation in a programming camp as a great learning experience: and "in the second year of high school I participated in Intel ISEF competitions and science fairs with EEE science fairs with the capstone project." The school provided different civic engagement opportunities with several organizations that helped students "look for better education in college and that's how I got the scholarship I got here." She had opportunities to visit universities and research centers to discuss scientific and engineering ideas like "the use of Nano membranes for water desalination in Zewail City."

Single sex schools. When asked about the single sex learning experience, Latifa was vocal in resisting that type of schooling. She said, "I think it would be better if both sexes were in the same school because I believe that this system and the way of thinking will be more inclusive of the two ways of thinking [male and female]." Latifa posited the reason behind the fact that girls' school "was relatively better at getting like high grades, while they [boys] win more robotics competitions and programming and like the technology stuff" is due to "a natural difference between the two [genders] in terms of foci and interests."

Muneera

Socio-cultural biases versus personal choices. Muneera's parents saw "engineering as having a lower status than medicine." They are a middle-class family who have only a high school education. All their children, other than Muneera, were either in or had graduated from medical school; "they wanted me to be a doctor and I wanted to be a doctor, too. Being an engineer didn't come to their or my mind at all." Munnera's parents did not even want her to join STEM school because "they didn't like the idea of a boarding school; they wanted me with them." However, while in STEM school Muneera decided to follow another track, engineering. When she expressed her wishes to be an engineer, she was viewed as out of the family norm and she even joined school of medicine for one semester before the call for engineering became irresistible. She joined a school of engineering in the United States after being accepted for a scholarship to fund her studies. Muneera's parents could not accept the idea that she would be an engineer and as Muneera reported "They still don't like it."

STEM experience: successes and challenges. The curriculum at the STEM school was "more open", in Muneera's terms. She argued that "in subjects like biology and chemistry at the school I had the opportunity to dig deeper into the things I was interested in and I really appreciate that." That helped her a lot at university but "this openness was not good all the time. In some cases, it was not very straightforward [clear]. The goals of the curriculum or what do we have to learn after studying this subject were not clear."

Muneera praised her teachers as supportive. She said, "teachers used different strategies, but the majority helped us to be independent learners. I can depend on myself now at college if I don't understand something." In some classes, learning "was

completely student centered where we did the entire presentation and the teacher was supervising us and only corrected us when there was something wrong." Assessment, however, was challenging as it was completely different to traditional schools and "there were no direct questions because you have to think. You don't have to memorize …they were super challenging the first two years." Muneera described assessments as "checking understanding not checking memorization." Challenging as it was, assessment was more manageable and conducive to learning than "memorizing a book from cover to cover and then forget everything after the exam is over."

Studying engineering while not being a mathematics major in high school was a challenge for Muneera, but she added "I am doing very well in math now" and that the skills from the STEM school rather than content were the reason as, "now [at college] when I am stuck in anything, I can teach myself... I do not need someone to teach me…I can go find books or the internet, or any way to understand so I really think this was great from the school. I learned how to work in a group, though I speak different [foreign] language [with accent] I had the strong personality to face challenges… I had learned a lot how to deal with people."

Extracurricular work. Muneera was interested in chemistry outside of school and she used to "interact with those responsible for the chemistry Olympiad. They were faculty from universities." In addition to her work in the capstone and extra effort needed to finalize projects she "visited a lot of universities and interacted with professors there**."**

Single sex schools. Muneera said, "if I went back I would prefer mixed schools." She had a hard time adjusting to the coed nature of higher education. Muneera did not only attend STEM high school in a single sex environment, all her pre-university

education life was single sex as well. Therefore, her ability to communicate with people from both sexes was affected by this long education experience. She explained "it was kind of the challenge when I came here. At the beginning I could not deal guys. It was hard because I didn't have experience. I did not go somewhere else. I was all my life in that single sex school system." However, her experience in the STEM school pushed them "to build the environment where we're supporting each other and learning from each other as different people coming from different backgrounds."

Discussion

From a cross-case perspective, a multilayered pattern of the supports and challenges that impact gender equity in STEM education in the Egyptian context were delineated (see Table 4.3).

Table 4.3

Supports and Barriers for Gender Equity in STEM Education that Emerged from the Qualitative Interviews

Themes	Subthemes (codes)
Family and social barriers and supports	Parents' support Stereotype threats and (gender) biases
Personal aspects	Self-efficacy Persistence Resistance
School level supports and barriers	Challenging curriculum Dynamic formative assessment Teachers' support Student centered teaching strategies Positive school environment Extracurricular activities Single sex school setting

The emerging themes in Table 4.3 show an intersectional pattern that includes the impact of the socio-cultural stereotype threats and biases that were diminished by the girls' resilience and the supports they received through their experiences at the STEM school. The girls did not concede to family and social pressures; they pursued their own dreams. In their emancipation journey, they showed high degrees of persistence, self-efficacy, and resistance to the social norms and stereotype threats at the family level and the immediate social network. In spite of the challenges they faced, the girls were able to navigate through this experience and benefit from it in their higher education engineering institutions.

These cases present a clear example of how the gendered roles are created at both the social and family level (Collins, 2015; Davies, 2003) and how they can be challenged. One way to challenge such fossilized gender roles, especially in the absence of social collective effort, is through consolidating personal traits like self -efficacy and persistence (Heilbronner, 2011, 2013; Liu et al., 2014). This is apparent in girls' defiance to the commonly accepted stereotype that it is hard for girls to be engineers. There seemed to be a strong relationship between the degree of bias and the level of resistance on the part of the girls; in the cases where gender bias was explicitly reiterated, there was markedly higher degrees of resistance to such stereotype threats (Davies, 2003; Steele, 2010). However, to address gender inequity in STEM, more work at the social level especially at school level is required (Baker et al., 2007; Baker, 2013; Lent et al., 2000; Lourens, 2014).

The school and teachers, in this case, provided additional support to the girls' personal resilience. All participants referred to factors at the school level that were

effective in deepening their interest in STEM, especially engineering. At the curriculum level, one of the common features was rigor and challenge. Not only did they refer to the challenging curriculum but the way it was delivered. The primary support came from the girl-friendly pedagogies they encountered at school. They referred to quality teachers utilizing student-centered approaches to teaching and learning, linking learning to real-world situations, group work, peer teaching, providing opportunities for students to increase their interest in STEM, linking content to prior experiences, providing first-hand experiences, encouraging discussion and reflections of the social importance of STEM fields, engaging students in collaborative learning, and a safe learning environment which all concur with research concerned with bridging the gender gap in STEM fields (e.g. Baker et al., 2007; Dare, 2015; Hill et al., 2010; Rosser, 1993; Schelinger et al., 2018). Teachers were also viewed by all participants as supportive, encouraging and caring being viewed by most of them as "parents". Research shows that quality caring teachers' support is crucial for a female equitable STEM experience (AAUW, 2000; Baker, 2013; Häussler & Hoffmann, 2002; Hill et al., 2010; Little & Leon de la Barra, 2009; Schellinger et al., 2018). Moreover, at the assessment level, participants agreed that assessments were not checking memorization; they were checking understanding which has helped them in their higher education institutions.

Last, although there was variation of perspectives around the idea of single sex schooling, there was consensus that it provided a safe, comfortable environment for learning where collaboration and slight degree of competition was present. However, from the input provided by the participants, single sex school experience in itself and by itself was not a guarantee for gender equity learning experience in STEM (AAUW, 2000;

Datnow & Hubbard, 2002; Kruse, 1996). In two cases, the outcome of the experience was not positive in the long term. It was hard for some of the girls to adapt to an environment where they had to deal with male and female students together in an academic environment. As a result, they felt frustrated at certain points for not being able to socially adjust to a coed institution environment though they were academically well prepared and maybe over prepared to these institutions.

The tension between providing a female-friendly, safe, and comfortable environment for female STEM students to work in; and at the same time nurturing the skills of being a part of a wider society where you will need to deal with all people was problematic. There is a need, therefore, for a balanced educational situation where girls are provided with the safe environment to learn and at the same time get involved in a socialization process that prepares them to the college level where a coeducational setting prevails both inside and outside Egypt (Little & León de la Barra, 2009; Penner, 2015; Reay, 2001). Indeed, in the new STEM schools in Egypt, girls and boys attend the same school with classes inside the schools segregated by gender. Though this decision was made for economic reasons because it is hard to build a separate STEM school for each gender in each city, it can be one way to alleviate the tension between providing the female friendly safe environment while helping consolidate the socialization process that they will need later on in their academic and professional life.

Conclusion

Gender inequity in STEM in Egypt is a complex issue. Girls' educational and career choices are deeply influenced by their family and community, however, personal aspects like self-efficacy, resistance, and persistence play a great role in students'

decisions to pursue STEM fields. School level factors like curriculum, positive environment, female friendly instructional approaches, teachers support are key factors as shown by the girls' experiences in the STEM school. An emancipatory effect of the STEM school experience has not only increased the girls' persistence and resistance to the gender bias and stereotype threats concerning STEM fields as male dominated but unleashed the girls' social and transformative potential towards building a more equitable society.

Chapter 5

The Professional Journey of STEM Teachers in Egyptian STEM Schools: Transformation and Identity Evolution in a Time of Transition

Introduction

The science, technology, engineering, and mathematics (STEM) movement in Egypt has been considered a "revolution inside a revolution" since it concurred with the January 2011 Egyptian popular uprising (Abuserie & Merlino, 2014; Rissmann-Joyce & El Nagdi, 2013). The goal was to change the stagnant status of the Egyptian education system characterized by outdated curricula, traditional methods, emphasis on factual knowledge and theory at the expense of hands-on practical activities, limited access to appropriate technologies, insufficient budgets (El-Deghaidy, 2017), an exodus of students from the science majors to the art major in high schools (Authors of Egypt pre-university education strategic plan, 2014) to a more student centered approach where critical thinking, innovation, and hands on work are emphasized (World Learning, n.d.; Ministry of Education (MoE), n.d). The development of STEM schools was central to re-envisioning STEM education in Egypt, with two model STEM high schools were established, a boys' school in 2011 and a girls' school in 2012. The schools' mission is to foster the development of socially responsible leaders who are equipped with capabilities of design, innovation and critical thinking as well as the knowledge and skills to address the grand challenges of Egypt (ECASE, 2013; Rissmann-Joyce & EL Nagdi, 2013).

Being a teacher in a STEM school has been a new experience for the teachers who started this journey seven years ago. Though they embarked on this new professional journey equipped with the old tools of the traditional system, there has been considerable

recognition of their role in providing effective education. The necessary shifts in classroom practice presented a steep learning curve for teachers and required developing an identity as a STEM teacher. Given the limited research on how teachers develop STEM identities (see chapter 3), exploration of the experiences of these Egyptian STEM teachers will provide additional information about the development of a STEM teacher identity. To do this, this study delineates the impact of STEM education on teachers' conceptualizations of the education process and their practices in the classroom in the light of three intersecting theoretical frameworks: *change theory* by Michael Fullan (2006), Bybee's (2010) decade of action in which he conceptualized the time frame for implementing a STEM initiative, and teacher identity research (e.g., Akkerman and Meijer, 2011; Alsup, 2006; Watson, 2006). Specifically, this study explores how Egyptian STEM teachers navigated the different aspects of the new system and coped with its challenges personally and professionally, the characteristics they see essential for a STEM teacher in the light of their experience in STEM schools, and in what ways their identities as STEM teachers have evolved. To this end, this study is guided by the following research questions:

1- How did Egyptian STEM teachers especially in the girls' STEM school navigate the complex STEM experience?
2- How did Egyptian STEM teachers' identity evolve over the course of the STEM experience in model STEM schools in Egypt?
3- What do Egyptian STEM teachers identify as being important characteristics of STEM teachers?

Literature Review and Conceptual Framework

STEM Education

With the increasing reliance on STEM as an education reform initiative in different parts of the world (Ritz & Fan, 2015), there is a need to understand the nature and meaning of this approach in terms of policies, programs and implementation (Bybee, 2010). STEM education underscores the importance of science; dealing with technology that is larger than information technology; recognition of engineering as part of K-12 education; more emphasis on 21st Century skills such as adaptability; complex communication; social skills; non-routine problem solving; self-management/ self-development and systems thinking; and an integrated curricular approach to studying grand challenges of this era such as energy efficiency, resource use, environmental quality, and hazard mitigation (Bybee, 2010; Morrison, 2006). A primary goal of these reforms is to enhance STEM literacy which includes "the conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues [within the framework of] integration of STEM disciplines" (Bybee, 2010, p.31).

Introducing engineering in the K-12 education system has been one of the biggest strides towards establishing a rigorous STEM initiative (Moore, Tank, Glancy, Kersten, Smith, & Stohlmann, 2014; Authors, 2012). A primary goal for integrating engineering was to "move away from [the] current siloed structure [of teaching STEM subjects] which may limit student interest and performance, toward a more interconnected whole" (NAE & NRC, 2009, p. 167).

Engineering is considered as the context for integrating science, technology and math into the classroom to simulate a real-world situation The role of engineering can be summed up as 1) providing a real-world context for learning mathematics and science; 2) providing design challenge tasks provide a context for developing problem-solving skills; and 3) promoting the development of communication skills and teamwork (Roehrig, et al., 2012; NAE & NRC, 2009). Additionally, as teachers integrate engineering and technology into STEM teaching model "they would further promote student interest in courses and occupations in the engineering or technological fields" (Liu et al., 2014, p.71).

STEM Schools

STEM schools have been developed across the world in response to the STEM education movement. Most often these schools use a selective admissions process, with criteria for admission tied to students' exam scores; science and mathematics background knowledge; and IQ tests. The criteria for selection may also include a student's interest in science and mathematics, academic performance, essays, special talents, accomplishments, and extracurricular activities (Dugger, 2010; Forman, Gubbins, Villanueva, Massicotte, Callahan, & Tofel-Grehl, 2015). However, research on selective STEM schools has largely been limited to "internal program evaluation, making it difficult to assess any causal inferences related to effective school features and practices" (Forman et al., 2015, p.8).

Global perspective

The STEM movement initiated in the United States has led to various attempts to replicate it in different places around the world (Bybee, 2010, 2013; Ritz & Fan, 2015;

Sanders, 2009). Countries all over the world perceive STEM education as a vehicle for preparing their future generations for a highly competitive global economy (National Science and Technology Council, 2013; Reeve, 2013; Ritz & Fan, 2015). This globalized perspective has an economic policy agenda that focuses on "enlarging the STEM skilled workforce to engage in research and development, industry innovation and effective responses to technological change; lifting the overall scientific literacy of the population; attracting more students to study STEM at senior secondary and university levels" (Gough, 2014, p. 446). Such efforts, prompted by the global financial crisis and intense competition, hopes that coordination and integration of STEM activities will help equip a workforce for dealing with the contemporary nature of business and industry, and encourage more school leavers to seek further training and employment in areas of engineering and science (Dugger, 2010; Sanders, 2009). Though the motives behind these STEM initiatives appear uniform across nations, implementation may be different given the political, social and technological history of each country around the world is different (Ritz & Fan, 2015; Williams, 2011). Thus, it is important that research considers the unique culture and situation within any particular country.

STEM experience in Egypt

Egypt's education system ranks very low in terms of the quality of education, being ranked 139 out of 140 in 2013 (Global Competitiveness Report, 2013) with slight improvement in 2017-2018 to rank 133 of 137 countries in the quality of primary education and 130 in the quality of education system as a whole (Global Competitiveness Report, 2018). In addition, students' achievement in international exams like The Trends in International Mathematics and Science Study (TIMMS) is comparatively low and

ranks in the under average segment (Provasnik, Malley, Stephens, Landeros, Perkins, & Tang, 2016; World Bank, 2010). Authors of the official Egyptian Pre-University Education Strategic Plan 2014-2030 (EPUESP, 2014) acknowledged the poor quality of the science and mathematics education in Egypt. According to the EPUESP (2014) students' interest in science and mathematics has been declining, and they concluded that "there was a reluctance of preparatory stage graduates to join the scientific section of the general secondary certificate with only 10% of them whereas the rest join technical secondary education or the literary section of the general certificate" (p.41).

Policy Window. The STEM reform initiative came into existence as a reaction to the negative state of STEM education in Egypt. And with the advent of the Arab Spring, especially the January 25th, 2011 Revolution, new hopes of genuine and real change flourished. The Arab Spring provided what might be called the "window of opportunity" for such a change (Steiner-Khamsi, 2006). The creation of STEM schools was initiated as an opportunity to make critical changes within the Egyptian education system. The first two STEM schools, a boys' school in 2011 and a girls' school in 2012, have been unique schools in the country and subsequently 12 more STEM schools have been opened. These schools were supported by the United States Agency for International Development (USAID). The first two model STEM schools were, and still are, boarding schools that use a centralized national, selective admission process (Authors, 2013) to secure an equal chance for all. The schools' mission is to foster the development of socially responsible leaders who are equipped with capabilities of design, innovation and critical thinking as well as the knowledge and skills to address the grand challenges of Egypt (ECASE, 2013; Rissmann-Joyce & El Nagdi, 2013).

Selection and recruitment of teachers in Egypt's STEM schools was a centralized process. The Ministry of Education (MoE) in collaboration with ECASE and Professional Academy for Teachers (PAT) in Egypt conducted the recruitment process. The MoE seeks to attract teachers with degrees higher than BA, or BSC; those who have participated in MoE funded short scholarships in other countries like the United States and Britain (PAT, n.d.) and provided higher compensation than other public school teachers to attract the most appropriate candidates. STEM teachers were provided with different professional development programs with at least one summer institute each year and several events throughout the academic year conducted by the ECASE STEM experts.

In spite of the critical importance of teachers' roles in securing a quality education process (e.g., Hargreaves & Fullan, 2012), Egyptian teachers have been historically marginalized in top-down decision-making processes regarding policy level issues and curriculum development (Meghahed, 2008). However, the STEM initiative promised a different paradigm where teachers were invited to play a role in curriculum design and subsequent implementation (ECASE, 2012) However, the challenges teachers faced in this new system were numerous. Among these challenges were attitude towards new teaching techniques, and students centered pedagogy, being open to students' critiques, using up-to-date technologies, using different forms of assessment, collaborative work (Abuserie & Merlino, 2014; Rissmann-Joyce & EL Nagdi, 2013), and more importantly, the deep identity changes these teachers have undergone in their professional journey as these STEM schools developed.

Conceptual framework

Bybee's Model: A Decade of Action. Creating an established STEM reform cannot take place overnight**.** Therefore**,** Bybee (2010) provides a model for adopting, sustaining and evaluating STEM education reform (see Table 5.1).

This study falls within the realm of first and the second stage in Bybee's (2010) model in which STEM education reform starts with introducing the STEM initiative which takes almost two years for instructional units to be designed, developed, and implemented. During that stage, the initial preparatory period encompassed the preparation of a whole new school system from organizational structures; hiring teachers and leaders and training them; admitting students; to providing schools equipment and resources. The second stage takes place within six years from the initiation of the STEM reform effort where policy changes, redesigns, reflections on successes and failures are deeply investigated. Egyptian STEM experience came to life in 2011; now in 2018 is the time to have that reflective look to help the process of redesigning both policies and practices in the light of teachers' reflections on their professional journey.

Table 5.1

A Decade of Action: phases and goals

Phase	Timeline	Goal
Initiating STEM education reform	Two years	Design, develop, and implement model instructional units
Bringing STEM reform to scale	Six years	Change policies, programs, and practices at local state, and national levels
Sustaining STEM education reform	Two years	Build capacity at the local level for continuous improvement of school science and tec. Programs
Evaluating STEM education reform	Continuous with a major evaluation in 10 years	Provide formative and summative data on the nature and results of the reform efforts

Source: Bybee, 2010, p.34

Fullan's change theory. Bybee's model requires that teachers change their practices to bring a STEM reform to scale. From a standpoint that views teaching as a relational sociocultural practice (Biesta & Stengel, 2016), this change in teaching practices is a result of a deep transformation process. In his framework, Fullan (2006) argues that for any educational reform initiative to succeed, a change in instructional practices inside the classroom, in addition to a deeper cultural change in the larger context, provides evidence of change. He introduces the term "lateral capacity building" where the individual stakeholders and their respective organizations embrace reform. With knowledge of desired changes and motivation, the larger context can begin to shift. However, in Fullan's (2006) model, some distractors may be barriers to changing context include unnecessary bureaucracy, collective bargaining conflicts, and managerial issues (Fullan, 2006).

Fullan (2006) described seven principles for ensuring a successful change: motivation; capacity building focused on results; learning in context for those enacting reform; capacity to change the larger context; reflective action; tri-level engagement; and persistence and flexibility. Motivation and engagement are vital for the success for educational reform, and all other premises depend upon motivated and engaged stakeholders. However, moral commitment to reform is not enough to produce change and must be accompanied by identity, capacity, resources, and support. Involving teachers in decision making increases motivation as teachers take ownership of ideas, which in turn increases readiness and interest in using learning-conducive practices in the classrooms (Hendricks, 2009). This can be manifested in different ways including establishing communities of practice that work together to develop their practices of teaching through a collaborative process of professional learning (Lave & Wenger, 1991). Cultural shifts are not easy as they require negotiation of new norms, structures, and processes. Modeling of desired values and behavior aids in the displacement of existing, undesirable norms (Fullan, 2006).

Tri-level engagement, including the school/community, district, and state, is essential to ensure educational reform efforts are successful and sustained. Fullan (2006) explained that complete alignment of the three is often difficult, but a goal of "permeable connectivity" can be realized when "mutual interaction and influence within and across the three levels" takes place.

Teacher identity. As part of the change process, teachers develop new or evolving identities as a result of the interaction between their personal experience and the new teaching situation or context they are placed in (Akkerman & Meijer, 2011; Watson,

2006). Research on teacher identity has explored how these identities are formed, the factors that influence changes of identities, and the role these identities play in students' and teachers' motivation and learning (Alsup, 2006; Franzak, 2002; Schutz, Hong, & Francis, 2018). However, research on STEM teacher identity is limited.

In this study, teacher identity is conceptualized as a dynamic, continually changing, and active process which develops over time through interaction with different policy, school, and classroom environments and those who work in them (e.g., Franzak, 2002). This is viewed as part of the change process that happens to teachers while undergoing new professional experiences leading to a process of creating new or multiple identities. The interaction between old established identities and new emerging ones results in an "identity fluidity" or "instability" (Beauchamp &Thomas, 2009; Day, et al., 2006). As part of Fullan's (2006) change theory, identity and ownership are two aspects that motivate teachers to change.

Methodology

Context and purpose of the research

This study used a multiple holistic case study to explore the experiences of Egyptian STEM teachers working in an Egyptian model STEM schools (Yin, 2014). The overarching purpose was to understand teachers' developing roles and identity in the Egyptian STEM setting (Yin, 2014). Each participant constitutes a unit of analyses in the case study. Case study research is chosen because of its utility to provide depth into contextually rich situations (Yin, 2014). The proposed case study is descriptive and analytic in nature as it closely examines and attempts to describe a phenomenon (roles

and characteristics of Egyptian STEM teachers) in a real-world context (STEM schools in Egypt) (Yin, 2014).

Participants

The participants were six STEM teachers of the model Egyptian STEM school for girls and an engineering specialist who was in charge of developing the engineering challenges for all STEM schools (see Table 5.2). The participants were selected utilizing a purposeful criterion sampling technique (Yin, 2014). The criteria include teachers of mathematics, science, engineering, and social studies who have been working in the model STEM school for girls for at least five years. This is to make sure that these teachers have had considerable experience in their STEM settings that they can share and subsequently to inform the research questions.

Table 5.2

Participants demographics

Name*	Age	Subject	General Teaching experience	Teaching experience in STEM school
Eman	50	Biology	27	6
Tamer	43	Physics	22	5
Ahmed	44	Math	25	5
Raafat	46	Chemistry	25	5
Ibrahim	45	Technology	20	6
Rabiey	46	Social studies	25	6
Tawfik	38	Engineering **	10	7

*Teachers names are their real names. It was difficult to get them unidentified as the school is unique and it would be very easy to identify them. They were given the choice by the first author to use pseudonyms but declined.

**Tawfik is not teaching at the girls' STEM school but he is responsible for the capstone in all STEM schools in Egypt.

Data collection

There were two sources of data for this study. The primary data source of this study was semi-structured interviews with the participants (Corbin & Strauss, 2015; Yin, 2014). Interviews were conducted in Arabic with the participants for ease of communication. Sample interview questions are included in Table 3. The secondary data source was document review / analysis of the MoE ministerial decrees outlining the goals, vision, and evaluation system used in the STEM schools (Hodder, 1994); other teachers' pertinent documents like lesson plans; and the ECASE available published reports on the project. In the light of viewing document analysis as "a systematic procedure for reviewing or evaluating documents—both printed and electronic material" (Bowen, 2009, p.27), these documents provided sources for what institutions (MoE and ECASE) envision as STEM education, STEM integration, and the purposes of the STEM initiative in the Egyptian context. as Hodder (1994) pointed out that documents have no meaning unless they situated in their varying contexts, these policy documents and reports were reviewed in the light of the teachers' input and experience in the STEM setting and their conceptualizations of STEM education, integration, and their roles in the STEM schools.

Table 5.3

Research questions aligned with interview questions

Research questions	Sample interview questions
How have Egyptian STEM teachers navigated the complex STEM experience?	1- How can you describe your journey in the STEM school; academically, professionally, and personally? 2- In what ways were STEM teachers in Egypt's model STEM schools involved in designing STEM curricula? 3- Have you been part of curriculum development in your subject area and/or the capstone? 4- Describe your role in the curriculum development, if at all. 5- What challenges and/or successes did they have while implementing STEM integrated curriculum? 6- How can you compare yourself professionally now and before joining STEM school?
How has Egyptian STEM teachers' identity evolved over the course of the STEM experience in two model STEM schools in Egypt?	7- What is your philosophy of teaching? 8- What is STEM from your point of view? What comes to your mind when you hear the word STEM? 9- How did it (philosophy of teaching) align with your conceptualization with STEM?
What do Egyptian STEM teachers identify as being important characteristics of STEM teachers?	10- How do you identify yourself as a STEM teacher? 11- What do you think are important characteristics of a STEM teacher?

Data Analysis

First, MoE and ECASE documents were reviewed to identify their conceptualizations regarding STEM education; STEM integration; the roles and characteristics of teachers in curriculum development; and regulations for teachers' recruitment. Though these documents were mainly utilized to provide background and context for the study, they were integrated in the qualitative data analysis of the teachers' interviews in different occasions.

Second, interviews were transcribed and translated from Arabic into English by the first author (from spoken Arabic to written English). They were then analyzed using

open inductive and axial coding strategies (Corbin & Strauss, 2015). An iterative process of inductive coding from the data, allowed for deep and comprehensive thematic analysis. Inductive open coding allowed themes to emerge organically from the participants and provided deeper understanding of specific contextual elements (Miles, Huberman, &Saldana, 2013), which lent themselves to a deductive iteration where the codes from the interviews were compared with the themes from the document analysis (Hodder, 1994) as well as elements found in previous literature. Axial coding was used to further disaggregate codes into salient and organized themes through constant comparative methods (Corbin & Strauss, 2015; Miles et al., 2013).

STEM School Context

As part of the initiation process (Bybee, 2010) of the STEM reform movement, the Egyptian Ministry of Education released a set of guiding principles to guide the development of STEM schools (see Table 5.4). The ministry of education also issued several ministerial decrees to organize students' admission, evaluation systems, school boards, hiring teachers and staff, curricula, the establishment of a centralized body in the MoE identified as the "STEM Unit", and finally establishing regional bodies in the Governorates where all STEM schools exist. The STEM Unit is headed by an MoE official and includes all the subjects consultants, together with representatives from the National Center of Educational Assessment and the National Center of Curriculum Development with the ultimate aim to oversee and expand the STEM experience in the country (MoE decrees 369/2011, 202/2012, 382/2012, 308/ 2013, 172/2014, 313/2015, MoE, n.d; World Learning, n.d).

Table 5.4

STEM schools design principles

Principle	Description
Principle 1	Value and consolidate progressive education practices, including project-based learning, to prepare students to demonstrate their ability to think independently, creatively, and analytically
Principle 2	Prepare students to be scientifically, mathematically, and technologically literate and proficient, able to apply their understanding to advance creativity, innovation, and invention with a real-world vision
Principle 3	Promote an environment of questioning, collaboration, and high level of Communication
Principle 4	Value and promote self-motivation, self-direction, and lifelong learning
Principle 5	Engage partnership to accelerate school capacity and broaden student, teacher, and administrative opportunity
Principle 6	Ensure all graduating students will be admitted to and competitive in a university and then in the Egyptian labor market as well as the world labor market
Principle 7	Foster the development of socially responsible leaders with consciousness and eye toward a more contemporary Egypt- solving the future while addressing the largest grand challenges

STEM curriculum in Egyptian schools

Curriculum for the STEM schools in Egypt, originally developed by the ECASE, was school-driven curriculum; i.e. its development was built on the feedback from teachers and students in the schools. The process was initiated in a Design Studio workshop that focused on the Egypt's Grand Challenges (Table 5.5) as the context for curriculum. Different stakeholders were invited including teachers, principals, and MoE officials. Thus, the proposed curriculum adopted a contextualized STEM curriculum framework that was based on Egyptian Grand Challenges as themes (ECASE, 2012, pp.12-13).

Table 5.5

Egypt's grand challenges generated in a design studio in 2011

No.	Grand Challenge
1	Address and reduce pollution fouling our air, water and grounds
2	Improve the use of alternative energies to reduce our reliance on extracted fuel sources
3	Address the exponential population growth and prepare for the impact
4	Improve urban congestion
5	Work to eradicate public health issues/disease
6	Recycle and retain garbage for recycling (now sent to Japan and China)
7	With this focus on STEM, our school will increase opportunities for talented graduates to remain in Egypt
8	Improve sources of clean water
9	Increase efficient use of our land through improved use of arid areas
10	Increase the industrial base of Egypt

A disciplinary curriculum for each science content area (physics, biology, chemistry, and earth science) and mathematics was developed with coordination across the disciplines in mind (see Table 5.6). In addition to the content area curricula, an integrated STEM capstone course was designed to help create a context for integration where students could apply their learning from their content courses to address one of Egypt's grand challenges (Authors, 2013; ECASE, 2012, 2014, 2016). Both the subject area curriculum and the capstone addressed a big idea of an overarching theme, and/or an Egyptian grand challenge. According to ECASE (2012) "these capstone projects provide the cornerstone of inquiry-driven, project-based STEM education and also are an important aspect of the STEM curriculum and standards framework" (p.12). The purpose of capstone projects was to bring rigorous, real-world STEM challenges into the classroom for all students to engage with inquiry learning in a manner aligned with the Guiding Design Principles of the Ministry of Education (Table 5.4). Table 5.7 presents capstone design challenges per grades. For instance, the theme for the first semester for

grade 11 was “change, equilibrium, and cycles”, and for semester 2 was “systems and feedback”; grade 11 students were working on capstone projects on recycling and water treatment (see Table 5.7) in semester 1 and on improving the scientific and technological base in Egypt for semester 2; year 12 students work on different challenges related to how the communication systems can be used to solve several problems (ECASE, 2014). For a sample capstone challenge write up see appendix E which presents details of one design challenge (grade 12) and how it was linked to the STEM content areas.

Table 5.6

Themes distribution per year and semester

	Year 10	
Semester 1		Semester 2
Matter, Form and Function		Energy Force and Power
	Year 11	
Semester 1		Semester 2
Change, Equilibrium and Cycles		Systems and Feedback
	Year 12	
Semester 1		Semester 2
Communication, Sensing, Information, Informatics		Theories, Models and Data

Based on ECASE (2012, 2013)

Table 5.7

Capstones per year per semester aligned with grand challenges

Grade10	**Grade 11**	**Grade 12**
Semester 1 **Egypt Grand Challenge**: Improve Use of Arid Areas, Urban Congestion	Semester 1 **Egypt Grand Challenge**: Clean Water, Reduction of Pollution; Recycling; Increase Industrial Base for Egypt.	One capstone per year **Flexible Grand Challenges (students choose one of the following)**: 1-Medical and Public Health Improvement
Semester 2 **Egypt Grand challenge** Improve the use of alternative energies	Semester 2 **Egypt Grand challenge**: Improve the scientific and technological environment for to Increase the industrial and agricultural bases of Egypt.	2-Reduction of Pollution 3-Recycling of waste for economic and environmental purposes 3-Increase and develop agricultural and Industrial Base for Egypt

The first implemented capstones were developed by external curriculum developers. The expert team developed a manual for teachers to use while implementing the capstones (ECASE, 2012, 2013). A gradual handing over of responsibilities for the capstone work to Egyptian teachers occurred (ECASE, 2014, 2016) and teachers in the schools assumed their roles as capstone facilitators, leaders, and designers.

Findings

From the vertical and horizontal data analysis of the different data sources (Miles & Hubberman, 2014), a set of themes emerged depicting the professional journey of Egyptian STEM teachers. These themes reflect the professional journey of the Egyptian teachers in the girls STEM school with all its successes and challenges, the evolution of their identity as STEM teachers and what they saw as important characteristics of STEM teachers. The themes presented henceforth encapsulate together the vision, policy, and work done at the level of the MoE and the ECASE with the input, practices, and comments from the interviewed teachers. Table 5.8 presents a summary of themes aligned with the research questions of the study.

Table 5.8

Summary of the findings per research questions

Research questions	Themes
How did Egyptian STEM teachers especially in the girls' STEM school navigate the complex STEM experience?	Transformative journey - Successes and challenges - Developing sense of ownership and belonging Developing STEM conceptualizations as part of the professional journey - STEM as system level reform - STEM as a pedagogical tool
How did Egyptian STEM teachers' identity evolve over the course of the STEM experience in model STEM schools in Egypt?	The tension between established and evolving identity - A developing nature of STEM teacher identity - Readiness for STEM
What do Egyptian STEM teachers identify as being important characteristics of STEM teachers?	Characteristics and roles of STEM teachers - Flexibility - Open to change - Collaborative - Innovator - Mastery of content knowledge and delivery tools Roles at the disciplinary and capstone levels - Teachers' roles in curriculum development - Community of practice (Trainers of teachers) - Building caring relationships with students

How did Egyptian STEM teachers especially in the girls' STEM school navigate the complex STEM experience?

Transformative journey.

Successes. Transitioning into the STEM school was not an easy task for all interviewed teachers. They were all experienced teachers in their prior traditional education settings with experience ranging from 10 to 26 years of teaching. They described the journey as sometimes thorny but ultimately y transformative. Tamer described the amount of professional development and learning he experienced his first year in the STEM school as far exceeding his seventeen- year- experience in a traditional

school. He started his journal as "physics teacher" but now after almost five years in STEM school, he climbed the professional ladder of STEM leadership to "head of department, capstone teacher, leader, and finally, capstone trainer of teachers[ToT} with a different mindset [towards teaching]" Eman described her "professional growth journey" where "through the different PD experiences, collaboration with teachers, interaction with students in their projects, [she]grew as a different teacher and a person." Tawfik described it as a "journey from skepticism in the abilities of students to tackle the challenging tasks and the teachers to implement such a curriculum to belief." He added that a few years later "when we looked back at the initial tasks [in the capstone] that we used to look at as challenging we started to think that they need to be modified to add some more rigor to them." Raafat considered his STEM experience as a "rebirth after being frustrated and burnt out after a 20- year experience as chemistry teacher in traditional secondary schools. I started to widen and deepen my concepts, and I started to find purpose and result of what I teach." Ibrahim found "light at the end of the dark tunnel after serving as a computer science teacher for more than 20 years." He added, "Here [in STEM school], I open the doors and facilitate learning which was impossible to do at traditional settings." He added that "though the first year was hard, it was full of learning. Every day you learn a new thing either form the Americans, your peers, or even students." Rabiey, the social studies teacher, was one of the first teachers to be involved in the capstone leadership work as a capstone facilitator and leader. Similar to the other teachers, he described that although the journey was initially difficult for him, "it was enjoyable. Every day, you learn something new. This experience opened the doors so wide to unleash my teaching aspirations that I could not do in my traditional school."

Challenges. The first MoE decree to establish the schools never mentioned the term "STEM" or its equivalent in Arabic, and nothing was specified in the document about what kind of curriculum to be used. Subsequently, teachers viewed the first year as a time of "random work" in Eman's words. The schools started in a time of political turmoil (during the 2011 popular uprising) and the girls school was not ready when students first arrived. Eman elaborated, "teachers and students had a hard time trying to figure out what to teach and how to teach in a STEM school before the ECASE took over."

Tawfik said, "we tried to brainstorm project ideas for students to work on" as STEM is fundamentally known at this time as project-based learning. Therefore, teachers were working on trying to devise projects that can accommodate their initial understanding of STEM. In the girls' school, "the capstone was postponed to the second semester for being not ready in terms of curriculum and resources" according to Rabiey.

Following the first year of the STEM school, great development has started with the start of the ECASE taking over technically and professionally, teachers developed greatly. Ibrahim described the learning and professional growth he had as "huge; we stayed after school time to work and receive trainings." Teachers had annual "summer professional development institute, onsite support and observation, online meetings with their American counterparts, and midyear training" as Eman elaborated. This was coupled with developing a "genuine collaboration culture among teachers especially from year 2 through year 5" according to Ibrahim.

Other challenges teachers had to struggle with in their STEM development journey was the vagueness around the final exams and university admission and how teachers

could support these students in their journey to enter higher education. Tamer said, “We have not got any released exams or past papers that we can use to help students get ready for the final exams.” He added that “The MoE officials justified this [not releasing any past exams] saying ‘once students see past papers, there is no opportunity for innovation’ which is not convincing to us.” In addition, there was a common belief that students at the STEM schools were geniuses and they needed to be given very hard exams, as Eman put it, “examiners think these students are geniuses so let us give them the hardest questions ever.” STEM students take exams different form the mainstream secondary education certificate according to the MoE decrees.

Developing a sense of ownership. As a result of the effort exerted by the teachers, the results students started to achieve in the various STEM fairs and competitions, increased public interest and media coverage, teachers had a time of satisfaction and developed a sense of ownership that their efforts were not in vain especially from year 2 through year 5. Ibrahim remembered the first few years of the experience where teachers “stayed in the school for long hours to help students in their work in the projects or in their subjects.” Ahmed, the mathematics teacher, explained that he “had to spend long time with students after school to help them in mathematics and cover the gaps in their mathematical knowledge between what they already know and what the new curriculum required.” Rabiey argued that despite the challenges that they “faced due to work pressure, higher demands from students, and bureaucratic problems, it is very hard to leave the STEM school and go back to my old school.” Eman considered the STEM school as

> home and students as children whose success gave a sense of satisfaction that she had fulfilled her job. Students who graduated from school- and are in colleges- are still in contact. I developed a family bond with them. I feel proud when they tell me that they mentioned their STEM experience with pride to their professors.

In the face of the different challenges they have at school, teachers still have hope to keep going, as Tawfik stated, “there is still hope and the momentum we had in the first years of the experience is still pushing us forward.” They had no intention to go back to the old teaching approaches, as Rabiey put it, “I can’t go back to my old school or methods of teaching.”

Developing STEM conceptualizations as part of the professional journey

The transformation that occurred to the teachers from the “traditional teacher” whose main aim was to deliver information to students to regurgitate on the final test to more progressive teachers with student-centered orientation extended to the conceptual level. They started to develop different conceptualizations of STEM and why it was important for them as teachers and for their students keeping in mind they had no prior knowledge or guidance from the MoE as to the nature of STEM. The teachers provided two general conceptualizations of STEM education; one as a policy level reform initiative and the second as a pedagogical tool to facilitate more student-centered teaching and learning.

System level reform initiative. At the policy level, STEM was conceptualized in the MoE and ECASE documents, as an educational reform initiative in which curriculum was based on integrated STEM units that utilized project-based learning and inquiry in a transdisciplinary manner (ECASE, 2012; MoE decree, 382, 2012).

Similarly, STEM was viewed by the teachers as an attempt to link learning to life and prepare students for the labor market. Tamer argued that

> STEM is an education system that makes students ready for life. Students link what the concepts they learn to everyday life issues and work towards solving problems. They do this through integrated curriculum, project- based learning through the design process, group work, having better communication skills and other skills like critical thinking essential for competitive labor market.

Rabiey argued that "STEM is a reform system that introduces certain strategies like project based learning and inquiry into the classroom in order to stimulate students to work more independently and critically to solve their country's grand challenges." For Eman, STEM was conceptualized as,

> always to study for life; link learning to life. It is an application of what students learn in schools to their lives. Students were always asking 'why do we learn these things?' STEM came with an answer which is to be used in their lives. Students are encouraged to contextualize what they learn at school to the Egyptian environment and how they can use this to solve their society's problems.

Eman, further, provided a spontaneous flow of different connections that came to her mind while teaching biology:

> The relationship between genetics and probability in math; the transfer of the nervous impulse in the nervous system which is electric in nature where the movement is a result of the difference in the electric potential on the two sides of the cell membrane which is part of both chemistry and physics

Pedagogical tool. On the other hand, Raafat considered STEM teaching approaches as a great tool to facilitate learning, "you hook the students and create desire for learning. You provoke students' interest through hands on work, discussions, collaboration etc." Ibrahim thought that "it is all about integration of different subjects in a meaningful context." During the different PD sessions and discussions with American team (ECASE team), Ibrahim, as a computer teacher, came to understand that the meaning of technology (T) in STEM was not restricted to information technology but "can be expanded to Fab Lab, robotics, electronics, and computer science." Through these different tasks, according to Ibrahim, "students got engaged in activities that support their learning and project design and implementation". From an engineering perspective, Tawfik looked at STEM as a gateway to provide 21st century skills. For him, the rigorous, challenging curriculum was one tenet of successful STEM experience:

> My conception of STEM is starting with a big theme, develop challenges that are related to real life situations for students to solve, and while trying to solve them, they will need to learn certain concepts in their disciplines and subsequently they will have to learn them. Therefore, students will learn the required content indirectly while learning much more valuable skills of independence, leadership, communication, and develop personal traits of perseverance, and patience.

How did Egyptian STEM teachers' identity evolve over the course of the STEM experience in model STEM schools in Egypt?

A developing nature of STEM teacher identity: The tension between established and evolving identity. Developing a STEM teacher identity in a new STEM school with lofty and challenging requirements was a complicated process for the

teachers. Though they viewed themselves, at the time of data collection, as accomplished STEM teachers, they still had tension between their identities as both being a disciplinary teacher and a STEM teacher.

Raafat, a chemistry teacher, stated that he was a "55% STEM teacher." He calculated this percentage by the amount of time he spent in teaching using STEM practices and pedagogies. He devoted the other part of the session to "content knowledge transfer using 'traditional' methods to ensure students are able to answer final examinations". Raafat was referring to the problems that occurred at final exams when students were required to answer some recall questions after the project was fully handed over to the MoE STEM Unit (SU). These changes of question types towards more content recall questions pushed students to seek private tuition outside of the school. Therefore, he wanted to convince students that they could find skills and knowledge inside the school. Not only did Raafat teach chemistry, but he, like all other interviewed teachers, provided support for "students in their projects throughout the capstone work through guidance, support helping in doing experiment." Likewise, Tamer, a physics teacher, thought he was "80% accomplished STEM teacher though I started the journey from scratch. I would consider myself as a STEM teacher with physics between brackets [STEM (physics) teacher]." Tawfik argued that he developed into an engineer with education underpinnings or what he called an "eduneer." He would like to be "referred to as a STEM eduneer or consultant to being called a STEM teacher" as he did not start his STEM journey as a teacher. However, Tawfik conceded that "this has not happened all of sudden it was a long journey and I am still evolving and learning." Eman, a biology teacher, was not an exception; she thought that she was

> 60% STEM teacher. STEM teacher and biology teacher are two faces of the same coin. In an 80- minute session, I spend around 60% doing STEM work; teaching strategies, checking understanding, using the backward design, using different assessment modes like KWL, etc.

At the other end of the continuum, Rabiey, a social studies teacher, identified himself as,

> a 100% STEM teacher. I do what a STEM teacher should do in classroom. I apply all the STEM teaching strategies, make the connections, and by time I started independently working on myself regarding professional development and helping other teachers and students. I developed from a social studies teacher, to a capstone teacher, and leader and I enjoy helping students in their projects even when I am not their capstone leader.

Ahmed, a mathematics teacher who was the school principal at the time of the data collection, argued,

> he has been aspiring to be the perfect model STEM teacher, hard as it was. I would rather be called a STEM teacher than a math[ematics] teacher as it is more comprehensive and inclusive. However, I still need a lot of skills, still need to learn a lot of things to do that.

Ibrahim, the computer science teacher, thought that he could identify himself as a STEM teacher as,

> it was more comprehensive. I think I am 75 % STEM teacher. Being a STEM teacher is larger in scope than a computer science; I do more than just teaching computer science. I help the girls to solve problems in their projects by guiding

> them to the best places to get the right answers to their questions or the technical help for their projects. For instance, I helped the girls in different projects to design certain solutions using programming language.

Readiness for STEM. To develop a STEM teacher identity in such a challenging context, there should be some indications of readiness or aptitude for the job. all interviewed teachers argue that the major indications include believing in the role students have in the learning process, and the ability to transition from being a disciplinary teacher to a collaborative STEM teacher. Before coming to STEM school, Tamer personally believed in motivating students to learn but "it was hard to do it well in the traditional school." Whereas in the STEM school this was the norm. Tamer argued, "Learning can happen better if motivation is created in the students' minds and hearts. The teacher's role is to create that motivation and get students ready for an effective learning process." In his view, STEM provided that opportunity for "students to embark on different learning opportunities that put them in the seat of the leaders and problem solvers of their country's grand challenges. Tawfik concurred that even before joining STEM schools he personally believed that "motivation drives learning. Therefore, students who join these schools need to be highly motivated, pushed and challenged to get the highest possible results. And this is what STEM requires." Rabiey believed that he had "a STEM teacher inside him" even before coming to STEM school. He used to

> try some of the active learning pedagogies like role play, asking students to do some research and prepare work for class, class discussions, but at a minimal level in my previous school. These were very effective strategies but not

> welcomed in that setting in contrast with the STEM setting where most of our work is based on such strategies.

What do Egyptian STEM teachers identify as being important characteristics of STEM teachers?

The answer to this research question draws on both the criteria the MoE set for selecting teachers for the STEM schools and what the interviewed teachers referred to as important personal and professional characteristics of teachers aspiring to or working in a STEM school.

The MoE envisioned that teachers being selected to work in a STEM school should be highly qualified academically and professionally. According to the MoE and ECASE, the teachers should have at least a bachelor's degree, with preference for those with a master's or PhD degree, have had an opportunity to travel abroad for professional training (funded by the MoE) to developed countries like the United States or Britain, and have worked as secondary teachers for at least five years. ECASE collaborated with MoE and Professional Academy for Teachers in Egypt (PAT) to conduct the first rounds of teachers' recruitment where the teachers went through a complicated selection process where, as Tamer described it:

> I sat for an online English reading and writing, had a face to face listening and speaking test, sat for a content area test, attended a summer institute of professional development, and were recommended to the subject consultant to meet him/her for an interview for final recruitment.

However, this process did not guarantee a teacher was compatible with the STEM teaching and learning environment. Some teachers, after being selected, could not continue because they lacked the skills and aptitudes to work in the STEM environment.

Characteristics of STEM teachers

Open to change and learning, flexible, innovative, resilient, and competent in content and pedagogy. From the point of view of the interviewed teachers, to be an effective STEM teacher, teachers should have "creativity, readiness and motivation to join STEM schools" as Tamer, Ibrahim, and Ahmed argued, which cannot be guaranteed in the MoE selection process as a lot of these qualities are not easy to figure out in the formal selection process based on tests and interviews. "The real test would be working in the school environment itself," in Tamer's words. According to Raafat, the STEM journey required a lot of resilience and "flexibility and being open for learning as well as having the patience and ambition to improve as a teacher." Tamer warned that if a "STEM teacher says I know everything, he/she would be a failure." Rabiey strongly concurred citing the different requirements STEM teachers need to do and the skills they need to master, "a teacher who does not know how to work in the capstone, understand what STEM is, or does not improve his/her English should leave STEM school immediately." Tawfik went on to emphasize the need for STEM teachers to have "the same characteristics you would like to see in a STEM student. Teachers at STEM schools should be researchers, and [be]close to the students." Ahmed added, "the STEM teacher needs to look at himself/herself as a student." Raafat argued that teachers chosen to STEM schools should have "good command of the content and the delivery skills to make that content accessible to students. That is why they should be should be open for

change and flexible." Ibrahim agreed that STEM teachers "should be academically strong in their disciplines." Such skills are not directly related to the academic degrees according the interviewed teachers. As Raafat pointed out, "Having a PhD or Masters in the content area is not a guarantee for being a good STEM teacher." Eman could not agree more, "Not every holder of master's degree or PhD is a good candidate, they are more theoretical and not open for learning." In her opinion, those teachers coming to STEM school with PhD degrees may think that they had nothing to learn; subsequently losing one of the biggest attribute for a STEM teacher: open for learning and to change. Eman thought that the "STEM system is pushing for professional development, otherwise, you won't keep up with the movement." The teacher cannot stop learning, as Ibrahim stressed, readiness to learn and patience are important characteristics; "teachers should be knowledge seekers and open for change, patient and able to engage in discussion with the students in these schools."

Technology literate. Ibrahim, from a computer science teacher point of view, stressed the technological aspects STEM teachers should be good at; they should be "technologically (IT) literate: there are teachers who come to the school and have no idea about emails, or using computer assisted learning. Unless those people coming show readiness to learn, they cause a big problem to the system." These technology skills are very important, according to Ibrahim, citing the different uses of information technology used in the teaching and learning at school like "doing research, corresponding with students, and giving feedback using electronic assessment systems, etc."

Collaboration. As pointed out by all interviewed teachers, collaboration is axial to success in a STEM setting. Tamer stated that

> you cannot continue in a STEM school if you can't collaborate with others or trying to show that you have all the truth and you are the best. You will be like a plastic gear in a machine of metal gears; you will be crushed out and repulsed unless you show flexibility and openness for learning.

Ahmed, a mathematics teacher, considered collaboration with teachers of other subjects necessary "for instance in physics and math. Our collaboration is crucial to make learning better for students as there are a lot of things in common." Rabie thought that one of the basic qualities of an effective STEM teacher was to think of himself or herself as "part of a whole with readiness to work together and learn from each other."

Developing a community of practice. Teachers started to think of themselves as a part of the change process not just a recipient. The teachers were working towards helping other teachers, both the new teachers coming to their schools and teachers in the newly established STEM schools as Teachers of Teachers (ToT). During that transformation process, teachers on both sides viewed themselves as learners in a community of practice with the domain (STEM teaching), the community (STEM teachers), and practice (professional development and collaborative work). Tamer felt so blessed that by this time he was "a ToT for new teachers in the new schools on the capstone". Tawfik worked not only with teachers as a trainer of teachers but developed a student network from senior students to help new comers in the capstone, "senior students who help other newly admitted students to understand how to work on their projects." Eman felt that she had the potential "to help other teachers in new schools and new teachers in her school."

Teacher roles

At subject level and at the capstone level. STEM teachers did not only teach in their content area, they also facilitated students' work in the capstone. In Tamer's words, the teacher became one source or reference for the student among numerous other references. He elaborated that a teacher's role is to use his

> experience and knowledge to analyze the students' work and direct for improved performance. Your role as a teacher is expanded to more like a moderator of learning or facilitator (in the sense that you are not doing everything or letting the student do everything, there is a certain level of balance where you know when you can interfere to help facilitate the learning process.

Raafat expounded on how his work in the chemistry laboratory differed in the STEM context,

> I can do the experiment in different styles that differ according to the audience I am targeting. A girl [student] with good prior knowledge is different from a girl without prior knowledge, different from a girl with prior knowledge and skills. I now have the teaching flexibility to deal with the different types of students.

Being able to integrate or connect your content area with other disciplines or in the capstone is a very important asset for a STEM teacher. In Eman's view**,**

> the teacher should be able to integrate and know a lot about other subjects and how they are connected. How the learning outcomes in the different disciplines be applied to the capstone. Sometimes, the students can figure this out for themselves by asking them to pinpoint which learning outcomes helped them in their project and in other cases the teacher should help students figure out these connections.

Teacher roles in curriculum development. The MoE and ECASE stated that the curriculum in the Egyptian STEM schools was school driven and based on a thematic paradigm revolving around Egypt grand challenges and within the parameters of the national science and mathematics standards and the international standards of STEM education (ECASE, 2014, MoE decree 382/2012). ECASE and MoE aimed to involve teachers in curriculum development in a variety of ways in the curriculum. This began with design studios where all stakeholders were involved, including teachers, to brainstorm the grand challenges. Teachers were also involved, with the help of STEM experts, in developing the different connections between subjects. The MoE further stipulated, in a revolutionary article in MoE decree 382/2012, that "faculty are entitled to decide the topics of each subject area that can achieve the learning outcomes of their curriculum all over the academic year. This is, in addition to, the project that students are entitled to do" (MoE decree 382/ 2012). In different occasions in their reports, ECASE showed the nature of teacher involvement in the curriculum design and iteration process to "leverage Egyptian STEM teachers to provide local contextualization to the content and to essentially create course material fully customized to Egypt." Given the complex nature of the contextualization process and "the mapping, alignment, publishing, and beta testing of the content will occur in waves over this year, with the first release from the publishers prior to the beginning of school year 2013-14" (ECASE, 2012). In addition to that, "feedback from these training sessions [with Egyptian STEM teachers] "has been taken into consideration to prepare for enhancements to the curriculum with a Design Studio scheduled in June [2014] to enable the next iteration of the Integration Curriculum (v. 2.0)" (ECASE, 2014).

Eman, as one of the early STEM teachers, reflected on her experience with curriculum design:

> I used to design my curriculum in the first year. Then with ECASE we had first draft in the design studio and then apply it and reflect on the application in the [following] design studio in the summer to redesign and so on for three years.

In addition to that, Eman explained that her "colleagues participated in developing STEM standards for Egyptian STEM schools which are not in use to the moment." Ibrahim referred to the process of creating the Egyptian STEM standards that happened in 2016, the last year of the ECASE tenure,

> new committees were organized to develop STEM standards [for each subject]. These committees included a faculty member from the university, a teacher, and a member form the MoE curriculum center. These standards were developed and sent to each subject consultant at the MoE and they are still there. [they have] never been sent to the teachers or the students.

Tawfik played a role in designing the capstone challenges with other Egyptian teachers and experts, with the full support of the ECASE. He "participated in capstone design challenges and after the ECASE left, [he] was in charge of developing them [design challenges] and making them deeper and more challenging." Rabiey participated in developing the social studies curriculum, "I developed the social studies learning outcomes with a colleague in the other STEM school." Raafat had the challenge of trying to settle the identity of the curriculum they should be using in the schools. He participated once in curriculum development where he was trying to figure out what kind of curriculum they are teaching in STEM schools: "is it [International English Certificate]

IG, IB, or Egyptian Secondary Certificate (Thanaweya Amma), I was told that we are studying/ teaching STEM." Ahmed objected to the thematic approach of having a grand challenge or theme and then building the curriculum around it. He argued,

> What I see is that these students come to you with mis-or no conceptions. Therefore, in the first year, you need to work on correcting the misconceptions and to widen their conceptual knowledge because they come from the basic education system that is solely based on memorization. Then you can start introducing projects and other STEM practices.

It was evident that Raafat was not heard because curriculum continue to be built around themes and grand challenges and students start capstone and project work from day one.

Developing a caring relationship with students. Ahmed remembered the days and night he spent with "students to help them catch up with the math curriculum," Eman spent "some nights with the students in their dorm when they needed some emotional support being away from parents for the first time in a boarding school." Capstone supervisors "spent many hours beyond school time to help students finalize their capstone prototype and scientific posters." Some teachers escorted students in their field trips and trips, according to Rabie, "to find materials for their projects, contacted experts and university professors to ask for their support and help in students' projects."

Bybee's (2010) decade of action. The STEM school has been in existence now for six years. This aligns with the first two stages in Bybee's (2010) conception of the time span and work requirements to initiate and bring a STEM reform to scale. The details of what has happened during each stage reveals the similarities and differences between Bybee's (2010) understandings and what really happened in the Egyptian experience

especially in terms of the challenges and successes teachers had during each stage. Table 5.9 provides a summary of Bybee's (2010) conceptualization juxtaposed with what really happened in the Egyptian STEM journey from the perspectives of different stakeholders: MoE, ECASE, and teachers.

Table 5.9

Parallel journey in the light of Bybee's (2010) decade of action

Bybee's Decade of action	**MoE**	**ECASE**	**STEM Teachers**
Initiating STEM education reform: *Design, develop, and implement model instructional units* Two years	Decree 369/2011 No mention of STEM	ECASE has not started before 2012.	2011 – 2012 Random work! Teachers were grabbling with what STEM really means and what it takes to implement it.
2012- 2012 (in boys' Stem school) 2012-2013 and 2013- 2014	Decree 202/ 2012 giving birth to the official name of the Egyptian Secondary Certificate (STEM Track) -Decree 382/2012 detailing all components and requirement of the STEM schools	Start work with design studio-grand challenges Curriculum development Start teacher PD	2012- 2013 A transformative professional experience for teachers started. Professional development programs by experts in STEM, more involvement in curriculum design and redesign.
Bringing STEM reform to scale: *Change policies, programs, and practices at local state and national levels* Six years	Decree 172/2014 starting the organizational structure of the STEM schools and creating the STEM Unit (SU) to oversee and manage the STEM schools all over the country.	More work on developing the curriculum based on teachers' feedback and more PD – more involvement of Egyptians to help transfer later on	Teachers continued participation in the curriculum development and leading the STEM experience in their schools. However, there were issues of relevance and sustainability in the experience.
		Continue the PD and curriculum	Teachers reached the peak of their

	MoE officials began to be directly involved in the process in collaboration with the ECASE. In 2016, SU began to control.	work – involving SU people	professional learning despite the administrative hurdles like changing of school principals and bureaucracy intrusion.
2014- 2015 through 2018- 2019 (this study) 2019 -2020	In 2016 MoE expanded the STEM experience by building more STEM schools in different Governorates. The number jumped to 14 in 2018- 2019 academic year	Transfer process from ECASE to SU	The curve started to go downward with the SU being more involved, some aspects of the mainstream education system started to creep into the STEM experience including, among other things, poor quality final exams, more focus on bureaucratic things than quality instruction, poor leadership.
		Work on generating STEM standards for Egyptian STEM schools started and standards for each content area was generated but not disseminated among teachers, students or the public up to this moment. Working to implement the vision of changing the larger context through supporting the MoE to apply STEM best practices to mainstream science and mathematics curriculum Preparing for the phase out	The increase in the number of STEM schools was not matched by corresponding increase of quality of the teachers selected. With the ECASE leaving, PD became of poor quality, no new lab materials or resources are coming making it hard for teachers to perform as expected. Despite the negative attitude prevailing, teachers are keen to continue the journey of transformation; they can't go back to the old traditional system. Their transformation is irreversible.

Discussion

Although chronologically, the STEM experience falls primarily in the second stage of Bybee's (2010) decade of action for establishing a STEM reform initiative, it has already revealed a deep transformative pattern for teachers whose STEM identity evolved in a challenging context. The evolution process and cycling between their disciplinary identity and developing STEM teacher identity is discussed in the light of Fullan's (2006) change theory, Bybee's (2010) decade of action and the literature on teacher identity (e.g., Akkerman & Meijer, 2011; Watson, 2006).

Change theory and Egyptian teachers STEM experience

The STEM teachers who participated in this study experienced a transformative change journey in their professional life that was initiated by the STEM reform project in Egypt. The journey started with great aspirations and lofty vision to establish a new framework for an education environment that is conducive to learning, creativity, and innovation which later would lead a wider transformation of the whole education system of the country (World Learning, n.d.; MoE, n.d). This effort created a motivating context for change in the culture of teaching and classroom practices of the participating teachers reflecting the major aspect in Fullan's (2006) change theory in which he argued that change in education that does not result in a change in the culture of teaching and classroom practices is futile. One of the biggest sources for motivation, at the time of the STEM initiation, was the wider calls for change in all aspects of the social, economic, and political life in Egypt concurring with 2011 Arab Spring era which provided a window of opportunity for education reform (Kingdon, 1995). This volatile state at the

political and social level became one of the sources of motivation for change in the country.

Within the education system framework, teachers were frustrated with the traditional approaches and welcomed a different mindset for work in their field; Raafat referred to this as a “rebirth” for him as a teacher. This motivation was enhanced by involving them in the curriculum design and giving them more freedom regarding what they teach in the classes as long as they achieved the learning outcomes. The result was a sense of ownership that had a positive impact on being keen to develop professionally to keep their school up to the expectations. Involving teachers in decision making concerning curriculum and instruction had a great positive effect on not only on consolidating teachers’ motivation for change (Fullan, 2006; Hendricks, 2009) but working towards building a community of practice within the STEM schools (Lave & Wenger, 1991) by collaborating in teacher training facilitating students’ work in their projects, and problem solving at the school level. As a result, the classroom practices reflected a change in the beliefs of teachers that students are the center and core of the teaching and learning process and they changed their traditional approaches towards more student centered and active learning pedagogies.

However, one of the biggest issues has been the coordination at the tri-level in Fullan’s (2006) conceptualization of change; in this case, the school teachers, the MoE, and the community at large. The MoE set a lofty vision for these schools, yet after the complete technical and professional handover of the schools to the MoE STEM Unit, the curve of teachers’ motivation started to go down reflecting the poor quality of professional, creeping of bureaucracy with little attention to the quality of teaching and

learning, mishandling of final assessment for students causing a lot of concern for the public shaking their trust in the STEM system, and a lenient approach to teacher recruitment to fill the vacancies in the increasing number of STEM schools. In spite of this, the transformation that occurred for teachers was so deep that they were committed to keep going and that "there is still hope and the momentum we had in the first years of the experience is still pushing us forward". They had no intention to go back to the old teaching approaches; as Rabiey said. "I can't go back to my old school or methods of teaching" reflecting another aspect of Fullan's (2006) theory which is the persistence and resilience.

Thoughts of all interviewed teachers about collaborative work in the STEM setting indicate that PD has little or no impact when it focuses on individual teachers without extending to the group of teachers with the aim of improving the education process as a whole. In this sense, teachers cannot survive in these STEM schools unless they are collaborative and open to change and learning as Tamer warned, "if a teacher thinks he/she knows everything, he/she will not be able to continue in STEM school. We learn a lot of thing every day from working together." This corresponds to a great extent to one of the tenets of Fullan's (2006) theory which is working on changing the larger context as a sign of cultural change. However, sustaining the STEM change (Bybee, 2010) has not been smooth due to different challenges including the "huge resistance to change" on the part of MoE officials described by the Egyptian Minister of Education Tarek Shawky (Shawky, 2018).

Teachers' identity

Six out of the seven interviewed teachers identified themselves as STEM teachers. This identity has evolved from nothing and took long time and effort. However, they still cling to their original identities as teachers of stand-alone subject matters reflecting multiple identities (Akkerman & Meijer, 2011; Cooper & Olson, 1996). The evolving nature of the teachers' STEM identities reflects the "unstable" and changing identity that is a result of the interaction between different personal and professional experiences (Schutz, Hong, & Francis, 2018; Watson, 2006) in an exceptional education setting. These experiences include handling different curriculum that require a lot of collaboration, flexibility, and open mindedness; being involved in curriculum development; teaching different students with different attitudes towards learning; the number of students' successes in the early stages both at the formal (100% graduation rates) and informal level (winning international prizes in science and engineering fairs); and finally, working with a different system of different assessments. These experiences garnered a change in attitudes and beliefs and created an irreversible sense of ownership. The intertwined motivation for change and the sense of ownership resulting from the identity formation process provides a strong evidence of how the professional journey of STEM teachers in this Egyptian STEM school has been so transformative where change has been accompanied by identity evolution, capacity building, resources for growth, and mutual support (Fullan, 2006).

One of the biggest findings of the identity development was the tension between teachers established identities as content areas teacher and their evolving STEM identity. The interviewed teachers set percentages of how much time they perform as a subject

matter teacher and a STEM teacher denoting “multiplicity” of identity (Zembylas & Chubbuck, 2018). While this is an established theme in the literature on teacher identity, in the case of the teachers in this study, it is a reflection of the context where the experience takes place and the requirements of the STEM reform. In other words, teachers tend to go back to silo teaching modes in order to cater for the context specific challenges like parents’ concern over their children’s score in the final exams which pushes them to search for private tuition to help their children (STEM students) in the examinations. While examinations are not intended to check memorization, nobody has ever seen a past paper of the exams to convince the parents that private tuition is useless in the STEM model. Therefore, teachers, in order to convince students, that they are qualified teachers and have a lot of content knowledge they resort to content delivery in the traditional ways causing the tension in identity.

Conclusion

The journey of the STEM teachers in an Egyptian STEM school was explored within this study through a conceptual framework of change comprised of Fullan’s (2006) change theory, teacher identity (e.g., Akkerman & Meijer, 2011; Watson, 2006), and Bybee’s (2010) decade of action to establish a STEM reform endeavor. All in all, this journey revealed a transformative experience in teachers’ professional growth and identity development, and deeper change in attitudes towards the education process and classroom practices in a student-centered context. Though this reform experience that falls within the first two stages of Bybee’s (2010) model of STEM reform, there were challenges that might cripple the sustaining phase of the STEM initiative (Bybee, 2010) due to issues with context like lack of previous experience in STEM education on the part

of the Egyptian education system, as well as the different forms of resistance to change in the Egyptian bureaucratic institutions (Ibrahim, 2010).

Within the parameters of Fullan's (2006) theory of change, motivation was created through a set of measures like providing an agentic environment for the teachers by involving them in the curriculum development process, taking their feedback seriously concerning the curriculum in the process of redesign, providing continuing professional development programs conducted by experts in the field of STEM education; and finally giving them leadership roles either in school leadership or professional development of other teachers. This motivation was reinforced through the resilience that teachers showed in facing the many challenges in their journey at the school level and the policy level alike. One of the major components of the change process that has been in place was how this change was reflected in teachers' culture towards education and classroom practices. This change in classroom practices was evident in using student centered pedagogies, project-based learning, and the sense of care for students' learning. Although expanding this change to the larger context of the Egyptian education system was one of the tasks of the ECASE and the MoE, the teachers grabbed the opportunity of being assigned the roles of ToTs to help teachers in their schools and teachers in the new STEM schools to join them in this transformative process. However, sustaining this change (Bybee, 2010), despite these transformative efforts, is in jeopardy due to the resistance to change at the bureaucratic levels in the Egyptian education system (Ibrahim, 2010; Shawky, 2018).

Implications

This study is the first of its nature in the Egyptian context that explored teachers' roles and identities in STEM formal settings. The findings of the study denote different implications at the professional and policy level. STEM schools provide an opportunity for professional growth for teachers and quality learning for students. Therefore, building more STEM schools will be great as long as qualified and prepared teachers are provided.

However, the challenges at the bureaucratic levels can kill the experience before it gets into the sustaining phase (Bybee, 2010) unless those in charge of the STEM education at the MoE level start working closely with teachers and listening to their concerns around curriculum, leadership and assessment issues. More pre-service opportunities for prospective STEM teachers would help reduce the identity formation challenges of those who come from the mainstream education to the STEM schools.

Chapter 6

Conclusion

With an interpretive and critical standpoint (Carr & Kemmis, 2003; Collins, 2004; O'donoghue, 2007), I embarked on understanding the nature of gender equity and the development of teacher identity in STEM education. In this research endeavor, understanding the development of teacher identity in STEM settings was a primary focus. This was accompanied by probing the different mechanisms that can be utilized to disrupt tacit power relationships and perceived social inequalities that hinder progress towards gender equity in STEM fields in the Egyptian context (Kincheloe & McLaren, 2002; Madison, 2005).

With the pivotal role of context in the sense making of the education phenomenon (Magnusson & Marecek, 2012), it can be argued that most educational experiences would be different when handled by different people and in different social and cultural settings where culture is perceived as "a set of meanings that humans have created and continually recreate" (Magnusson & Marecek, 2012, p. 47). In this sense, the different requirements for both STEM teachers and students mean that STEM possesses a unique culture of its own. Therefore, studying STEM education across two different geographical and cultural contexts (American and Egyptian) allowed for deeper insights on how global/universal educational ideas and perspectives evolve in different cultural settings. However, results of the three studies that comprise this dissertation show that while context and sociocultural dimensions are closely connected with variation in conceptualizing and implementing STEM education, there remain some common dimensions that reveal the global nature of STEM education.

STEM has been regarded as a reform initiative in different countries in the world, usually emanating from an economic, competitive point of view (Breiner et al. 2012; Williams, 2011), utilizing similar teaching approaches across classrooms (Morrison, 2006, Rissmann Joyce & El Nagdi, 2013). Indeed, more and more countries are looking at STEM as a gateway for quality education.

In this chapter, an analysis of the commonalities and differences among the major themes across the three studies is introduced keeping in mind the different contexts. As a result of this analysis, two main findings emerged. First, there is an emerging STEM culture where participants are found to have developed some commonalities pertaining conceptualizations of STEM education, STEM teachers' characteristics, and nature of STEM teacher identity development. The other major finding is the context specific aspects like gender issues in STEM and the nature of the challenges that provide localized knowledge.

An emerging culture of STEM education

STEM conceptualizations. STEM was generally perceived by teachers in the Egyptian and American setting as both a systemic reform process and a pedagogical tool to facilitate students' learning. Given the diverse educational settings they worked in, the American teachers had more tendency towards looking at STEM as an opportunity for inclusion and engagement. However, in all cases, integration and student-centered pedagogies were conceptualized as pivotal parts of STEM education.

In the case of the American teachers, STEM was not seen as a groundbreaking policy issue to reform education; it was viewed as a new curricular effort to be integrated into their existing teaching. Though teachers had to work on aligning the existing

curriculum to STEM practices, the standards on which that curriculum was based were not far away from STEM requirements. The teachers' main concern was how to be prepared as STEM teachers and the need for more work on the instructional level. On the other hand, Egyptian teachers went through intensive costly professional development opportunities sponsored by the USAID which paid off to a great extent.

Working towards a more inclusive and equitable STEM environment was one of the salient results across studies. In the American context, Falconer and Nodack, the two schools explored in chapter 3, had a very diverse population where minority students and students qualified for free or reduced lunch comprise almost 90% of the school student population. STEM was introduced in that setting with inclusive and equitable orientations. In the Egyptian context, the work towards creating a girl' STEM school to parallel the boys' STEM was a similar move but from the gender equity perspective. In addition to that, the school was so diverse and inclusive in the sense that the students came from different parts of the country to a boarding school for girls in Cairo. They came with different cultural and socioeconomic backgrounds. In this sense, equity and inclusion are salient in both studies but from different perspectives that vary according to the context.

Transformative nature of STEM experience. Despite the different contexts, the three studies denote some global commonality in the recognition of the transformative nature of the STEM experience. Looking at STEM as an opportunity to change and develop at the professional and personal level was evident in all cases. The push for change was noticed in the way teachers embarked on adopting student centered pedagogies and helping other teachers through different collaborative activities. What

was surprising was that teachers in both contexts used the same language to express that transformation. For instance, in the United States, Calvin referred to his work towards becoming a STEM teacher as saving him from being “burnt out” as a teacher after just four years of experience. Likewise, Raafat described it as a “rebirth”; Ibrahim referred to “light at the end of the tunnel”; Eman talked about the “professional and personal growth opportunities” she underwent as she embarked on the STEM experience.

During the transformation process, teachers from both countries viewed themselves as learners in a community of practice. Being open to change with focus on learning at the content and pedagogical level was one of the assets of a successful STEM teacher. The emphasis on collaboration as an essential asset for effective STEM teachers is common across all the three cases. Graduates of the Egyptian STEM school referred to how their experience in STEM enhanced their collaborative skills while Egyptian teachers designated collaboration as a basic aspect for the success of a STEM teacher; so did the American teachers who viewed collaboration as axial in adopting the team teaching model rather than the single teacher for all STEM disciplines.

The experience Egyptian STEM graduates had in their STEM school was also transformative. The girls unanimously viewed it as the greatest transformative experience they had in their lives. Not only was their interest in STEM fields enhanced, they developed several 21st century skills like communication, being independent learners and researchers, working in a group, critical thinking and problem solving. These skills have had major impact on their college work.

Identity evolution. The results in both studies on STEM teachers in Egypt and the United States denote the multiplicity, evolving dynamic nature, and context specific

process of developing a STEM teacher identity. In spite of the current state of uncertainty in the Egyptian setting, teachers developed a degree of irreversible change and ownership. They saw that it was extremely difficult for them to leave STEM schools and go back to the traditional schools they came from. They continue to work towards helping students and other new teachers who join their schools or those starting work in new schools leading to having more impact on the larger context (Fullan, 2006). While in the American case, while still grabbling with the concepts and how to put these in action in their classroom practices, they started establishing STEM teams and held regular meetings to exchange views and ideas and discuss their plans for implementing STEM curricular units in their classrooms. This was leading towards an initial form of ownership that might develop by time if leadership in the schools provide the amicable atmosphere.

Teachers are still experiencing the tension between being teachers of their original subjects and the aspiration to be a perfect STEM teacher or as Tamer put it "a STEM teacher with physics in brackets." The same thing was evident in the case of the American teachers; they referred to how they were developing an emerging STEM identity but still experiencing a professional and moral attachment to their original subjects. This was coupled with an acknowledgment that they had a preference to be identified as STEM teachers as a more comprehensive framework. Therefore, whether emerging or established, teachers' identities were reported to reflect the major findings of teacher identity research of being "unstable" and "developing" that result from the interaction between different factors personal and professional (Akkerman & Meijor, 2011; Watson, 2006). However, the degree of development and the movement towards

the established identity differ from case to case even in the same context with the Egyptian teachers tending to be moving towards a more established identity having been teaching in a STEM school for longer periods than their American counterparts. The different justifications regarding what hinders their aspirations to be a STEM teacher again denote the different context. In the case of the Egyptian teachers, different issues cripple this evolution including content delivery for the final exams, lack of resources; but in the case of the American teachers, it was partially due to their need for more learning and knowledge of the system as they still in the early stages of implementation; in stage one in Bybee's (2010) decade of action. Therefore, they needed more professional development to get to the desired destination of a STEM teacher.

Characteristics of STEM teachers. There was consensus in both contexts for the attributes of STEM teachers. Flexibility, openness to change, collaboration, and preference for student centered pedagogies were emphasized in the three cases. The graduates from the STEM schools praised their teachers' flexibility and care, while noting that the teachers needed more PD to be better prepared for the STEM endeavor. Egyptian teachers referred to the necessity of having a teacher ready to learn with an open mind, competent in content and pedagogy, and caring for students. Likewise, teachers in the American schools concurred with these attributes and added that teachers should be ok with failure (at the student and teachers level) as an opportunity for learning.

Collaboration is the essence of success for STEM teachers in the team teaching model. In this model STEM work is distributed in terms of teaching tasks, supporting students' projects, helping other teachers in areas they are not the expert in. For this to

happen in a seamless manner, a great degree of coordination, common planning, and peer learning is required. Hence, collaboration is being ready to help and learn from others is essential in a setting where "keeping knowledge to yourself is damaging to the system" as Eman and Calvin said.

Centrality of context

When implementing a STEM reform, these different countries adjust the reform to fit their own cultural and socioeconomic needs and conditions (Ritz & Fan, 2015; Williams, 2011). The question has been asked if there is a global version of STEM that can be replicated in any country.

Challenges. Challenges in the American context are different from those in the Egyptian one. In the American case, the focus on STEM was at the school level though there was a federal support and the fact that the NGSS incorporate the STEM practices. However, the schools are not committed to adopt these standards. In the American case, adopting STEM as a reform approach depends, in some cases, on how the school principal conceptualizes STEM.

On the other hand, in the Egyptian context, the reform process is a centralized one; the STEM schools are directly affiliated to the MoE. Therefore, the leadership or management problems and challenges are not only restricted to the school level. Therefore, though the challenges may look uniform in two cases like the Falconer and STEM school in Egypt, the essence of challenges vary according to the context. Leadership problems in the Egyptian context are not only restricted to people at the school or district level; it is a deep bureaucratic network at the MoE which renders dealing with as a big challenge. Therefore, the nature of challenges in the Egyptian

context is more related to resistance to change at the bureaucratic level, limited resources, and sustainability. Eman argued that a "school leader should have the same characteristics needed in a STEM teacher, should understand want STEM is and what it takes to implement a STEM curriculum to avoid the different conflicts with them[teachers]."

In the unique Egyptian setting, there is a certain concern that the STEM reform (schools) will be short lived and might not be able to continue with the same quality. This cautious view is the result of experiencing a lot of efforts to fix a failing education system through using different imported reform systems from foreign countries that look shiny at the beginning but when the foreign support stops, the project is over (Ibrahim, 2010; Ginsburg & Meghahed, 2008). This can be exemplified in the different parallel levels introduced to the system. In this sense, for some teachers and students, STEM is looked upon in this context of the series of reform experiences which did not have much effect on the mainstream public education schools that comprise up to 85 % of the students' population in the country (Ibrahim, 2010; Ginsburg & Megahed, 2008). This created a sense of uncertainty of whether Bybee's (2010) STEM sustaining phase will come to light.

Gender equity and diversity. When asked about their opinion of the single sex school experience, it was evident that the participants in the gender equity study have developed different conceptualizations for the experience in the single sex school as they have studied in the higher education setting. Three of the participants had spent their entire education life in single sex schools. Once they were in coed settings, they started to develop different conceptualizations ranging from having no preference to preferring a

coed setting where more interaction and communication flourish. In all cases, this was coupled by the insistence that a single sex school is not a guarantee for success in STEM work unless it is provided with quality instruction, challenging curriculum, different modes of assessment, positive school environment, and female friendly approaches which cannot occur with having well prepared teachers who understand the context of STEM as well.

In the American context, the two schools explored were coed schools. It was hard to find a segregated public school in the American context. The diversity observed in the American schools in terms of gender, socioeconomic status, and color poses different challenges regarding using culturally relevant pedagogies and more inclusive environment for students who come from marginalized groups like people of color and immigrants who are mostly English language learners.

While female representation of Arab, including Egyptians, in engineering and physical sciences is the lowest in the world, it is not much better in the United Sates. Women accounted for only 24% of bachelor's degrees in the fields of physics and engineering in 2016. This low percentage is likely related to young girls' K-12 education experiences, particularly their experiences prior to high school, during which time young women's perceptions of Science, Technology, Engineering, and Math (STEM) and STEM careers are formed (Dare, 2015). Research and practice show that the low female representation in certain STEM fields is a result of not their abilities as their achievement is not lower than that of their male counterparts, but their perceptions which formed in the formation years of the students (Sikora & Pokropek, 2012). Therefore, more effort is necessary to encourage the adoption of female friendly instructional practices and

provide a more positive environment that encourages more cooperative work among students.

Finally, the studies in this dissertation were not, and are not intended, to be a comparative work. However, a look at the conclusions of the three studies reveals a picture of STEM across the globe- at least in these two countries both as a reform pedagogical approach and a system-level reform initiative. There is a certain extent degree of agreement in regards to different themes concerning the importance of STEM as a reform initiative from the point of view of students and teachers in both contexts, the transformative power of STEM education, the need for more work on aligning the teacher PD with the needs of STEM, the need to have teachers who have personal philosophies aligned with STEM workplace, and STEM as a means for equitable education for female students. However, there has been some context specific aspects that emerged across the three studies including the nature of challenges that face the Egyptian teachers in STEM settings and the gender related issues are manifested across the three studies.

Implications

Leaders in STEM schools are second only to teachers in an effective education system. They should be viewed as such. The same criteria used for teacher selection should be applied to leaders in STEM schools and all leaders that are responsible for STEM at the policy level. Leaders of STEM schools should be from among those who understand what the STEM model implemented in their schools is and how to start and maintain a collaborative, friendly, conducive learning environment in their schools. This is, in addition to, their work on developing curriculum and selecting teachers whose personal philosophy of teaching aligns with STEM philosophy.

STEM teacher preparation programs need be crafted in a way that prepare STEM teachers to work in a STEM school setting. All the teachers who participated in the studies did not have any STEM preparation as teacher candidates; they all came from the mainstream education prepared as disciplinary teachers. Most of them spent considerable time teaching in the mainstream education systems but moved to or asked to implement STEM curriculum in STEM schools. The shift, though enjoyable for many, was a steep learning curve for most. This can be alleviated through designing programs for teachers to be employed in STEM schools where teaching skills and dispositions required from teachers in these STEM settings are to be the focus of these programs.

Providing continuing professional development in a STEM setting is necessary for the sustainability of that reform initiative. One goal of such PD programs should be enhancing the collaborative spirit among teachers to create a community of practice that would ensure a certain level of quality instruction inside these schools. These programs should consolidate community of practice elements like peer learning, encouraging critical friends' groups, and cognitive coaching. Therefore, as teachers join STEM schools, probably a good scenario is that the "natural selection" metaphor Tamer referred to in the STEM is in action where teachers who were "crushed out of the system due to their inability to adapt to the system's requirements especially collaboration and flexibility", the same two characteristics most American teachers stressed regarding who would fit in STEM school as a teacher. In case there are not such PD programs, the motivation for change and sustainability would go down.

Limitations across the three studies

Per the qualitative nature of the case studies comprising this dissertation, different limitations exit. These limitations can be attributed to limited sources of data in each study due to the sampling technique utilized, the lack of classroom observations to match teachers' conceptualizations with their classroom practices, and inclusion of Egypt based female graduate of the Egyptian STEM school who actually pursued science and engineering tracks in the Egyptian higher institutions.

Data sources and sampling. In the *Gender Equity in STEM Education* study, five participants were the primary source of data regarding their experience in the STEM school. This number would have been bigger; however, this would be beyond the scope and abilities of the author of this dissertation as including more participants would require more time and other researchers to help. In addition to that, the selected graduates were appropriate as they were in the United States during the time of the data collection providing a convenient setting for the author who was living in the U.S. Further work can be done to include graduates in the Egyptian higher education institutions.

While the participating teachers in *the Developing STEM teachers' Identity at Emerging STEM Schools* study in the U.S. context were representative of the STEM teams working in the two schools explored, they still lacked a mathematics teacher. The reason behind that was that there was no mathematics teacher willing to participate at the time of the data collection. One mathematics teacher was later interviewed but after the study was ready for publication.

In the study of *The Journey of Egyptian STEM teachers*, the teachers represented all STEM disciplines, as well as social studies. They, nevertheless, were six teachers of

the school population of teachers. This was due to the selection criteria utilized by the author that restricted the choice to those teachers who had enough experience in the STEM school that allow them to reflect on their journey in the STEM school.

Classroom observation. One of the major limitations of the studies on teacher identity development was that there was no chance for classroom observations. In the *Developing STEM Teachers Identity at Emerging STEM Schools* study, the purpose of the study spoke very clearly to this as it did not intend to extend to classroom practices at this stage. As an emerging experience, the scope of the study was to explore self-reported conceptualizations of how the teachers see themselves in a STEM setting and how this identity developed in the short period of time. Further work will be directed to matching these conceptualizations with actual classroom practices. In *The Journey of the Egyptian STEM Teachers* study, the author was part of the experience before he started this program. He had good idea about what the teachers say and could figure out if there was any mismatch between the sayings and the actions. However, further work will be needed to investigate the STEM experience in full including first hand observation of classroom practices.

Future Research

This three-paper dissertation is a starting point in a research endeavor that would lead to more research work on identity and equity in STEM, especially in the Egyptian context. More work will be needed to follow teachers' continuing development in Egypt's new STEM schools, especially exploring the sustainability stages of the STEM movement. Classroom observations and analysis of teachers' practices and students work

will be a further step to verify and scrutinize teachers developing or developed identities and how this is reflected on students learning.

More work will be needed to follow up the participants of the gender equity case study to see if their pursuit of STEM will end up with getting a higher education STEM certificate or continue their journey into STEM careers. The future work, in this regard, will explore the future careers the female STEM graduates will choose and how these choices were affected by their studies in STEM settings at both the high school and higher education levels.

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Appendixes

Appendix A

Developing STEM Teachers Identities at Emerging STEM Schools

Interview protocol

1. What does STEM mean to you? When you hear the word STEM, what comes to your mind?
2. Do you identify yourself as a STEM teacher? Why? Why not?
3. How do your ideas about STEM align with your philosophy of teaching?
4. What do you think are important characteristics of a STEM teacher?
5. How is being a STEM teacher different from a (science/math/art/social studies) teacher?
6. How can you see yourself as different from other teachers, if any?

Appendix B

Gender Equity in STEM Education: Egyptian STEM Girls: An intrinsic Case Study

Interview protocol

1. How would you describe your experience at the STEM school?
2. How was working with girls from different backgrounds for you? What was it like?
3. What was special about the school's curriculum?
4. Describe how were teachers' teaching approaches different?
5. How was assessment different from those in your previous school, if at all?
6. Tell me a little about your family? What is your father's occupation? Your mother's?
7. What were your major interests before joining STEM school, literature, mathematics, science?
8. If the MoE decided to build more STEM schools, what would they consider?
9. Tell me a little bit about how you thought about mathematics and science in middle school?

Appendix C

The Professional Journey of STEM Teachers in Egyptian STEM Schools: A journey of Transformation and Evolving Identity in a Time of Transition

1- How can you describe your journey in the STEM school; academically, professionally, and personally?
2- In what ways were STEM teachers in Egypt's model STEM schools involved in designing STEM curricula?
3- Have you been part of curriculum development in your subject area and/or the capstone?
4- Describe your role in the curriculum development, if at all.
5- What challenges and/or successes did they have while implementing STEM integrated curriculum?
6- How can you compare yourself professionally now and before joining STEM school?
7- What is your philosophy of teaching?
8- What is STEM from your point of view? What comes to your mind when you hear the word STEM?
9- How did it (philosophy of teaching) align with your conceptualization with STEM?
10- How do you identify yourself as a STEM teacher?
11- What do you think are important characteristics of a STEM teacher?

Appendix D

Abstracts

1- (Chapter 3) Developing Identities of STEM Teachers at Emerging STEM Schools

With the expansion of science, technology, engineering, mathematics (STEM) schools all over the United States and the world, new roles for teachers are being created, and with these roles, new identities are evolving. However, these roles and identities remain an ill-defined area in STEM. The purpose of this paper is to explore the developing STEM teachers' identities in emerging STEM schools answering two research questions: 1) How do teachers define their roles as STEM teachers within a STEM school? 2) What do teachers identify as being important characteristics of STEM teachers? A multiple case study design is used to explore the research questions within a bounded context of two emerging STEM schools. Data for this study were drawn from semi-structured interviews conducted with 8 teachers from two developing STEM schools within a large urban district in the Midwestern United States. Teams of teachers at each of the schools worked throughout the year to develop and implement their vision for STEM. Using an inductive data analysis process, three major themes that characterize a STEM teacher identity emerged. These are the unique nature of STEM teachers' identity; professional characteristics of STEM; and personal characteristics of STEM teachers. Collaboration, flexibility, awareness of students' needs, and advocates of equity and inclusion were identified as pivotal characteristics of STEM teachers. This study concluded that STEM teachers' identity can be viewed as a dynamic evolving process that results from the interaction of personal and professional traits within new educational experiences

exemplified by the STEM endeavor in their schools. An alignment between teachers' personal philosophy and STEM understanding is essential for the success in teaching in STEM schools.

Keywords: Teacher Identity, STEM Schools, Case Study, STEM teachers, Grounded Theory

2- (Chapter 4) Gender Equity in STEM Education; The case of Egyptian STEM Girls: An intrinsic case Study

This paper explored gender equity in STEM education within the context of an Egyptian STEM school for girls. An intrinsic case study design was used to explore the experiences of girls in STEM from a socio-cultural perspective within a critical theory framework. The participants were STEM school graduates currently enrolled in engineering tracks in higher education institutions in the United States. Though STEM fields, especially engineering, are stereotyped as male dominated fields, Egyptian girls at a Cairo single sex STEM school pursued further studies in STEM fields. Findings show that gender gaps in STEM fields in Egypt and girls' education and work decisions were deeply influenced by their childhood background, family education level, socioeconomic status, and idiosyncratic factors like self-efficacy and resistance. At the school level, teachers' support, challenging STEM curriculum, dynamic formative assessment, student centered pedagogies, female friendly teaching approaches, and a positive school environment played a great role in developing Egyptian female students' potential to pursue STEM fields in higher education institutions.

Keywords: Gender equity, STEM education, Case study**.**

3- (Chapter 5) The Professional Journey of STEM Teachers in Egyptian STEM Schools: Transformation and Identity Evolution in a Time of Transition

Using a multiple holistic case study, the professional journey of STEM teachers in an Egyptian STEM school was explored. The study was initiated as a response to the growing STEM experience in Egypt both in terms of the growing number of schools, number of students admitted, and the effect of this experience on the overall education system in the country. Egypt started the STEM experience in 2011 with one school and now there are 14 schools all over the country. Viewing teachers as the backbone of the STEM experience and teaching as a relational sociocultural practice (Biesta &Stengel, 2016) , this research explores their professional journey in the STEM setting and is guided by following research questions: 1) How did Egyptian STEM teachers navigate the complex STEM experience? 2) How did Egyptian STEM teachers' identity evolve over the course of the STEM experience in model STEM schools in Egypt? 3)What do Egyptian STEM teachers identify as being important characteristics of STEM teachers? Using inductive and deductive data analysis of semi structured interviews with teachers, document review of Ministry of Education decrees, and the published reports of Education Consortium for the Advancement of STEM in Egypt (ECASE), teachers were found to have undergone a deep transformative change process from the traditional teacher into teachers with progressive mindset and different student-centered classroom practices. The teachers developed different conceptualizations of the STEM education, stressed the importance of collaboration, critical thinking and motivation for teachers seeking to work in a STEM setting, and considered themselves moving towards established STEM teachers' identity. Despite several challenges like limited resources,

creeping of some ailments from the traditional system like bureaucracy and private tuition, the teachers still possess the energy for continuing that irreversible professional growth that eventually would have an impact on the larger context of the Egyptian education system.

Keywords: STEM education, STEM education in Egypt, education change, teacher identity, case study

Appendix E

Capstone design challenge write up

Grade 12

Capstone Challenges
2017-2018

Grade 12 Semester 1, Communication in Biological, physical, Chemical, and industrial/agricultural Systems to improve the public health

Grand Challenges:

- **Medical and Public Health Improvement**
- Reduction of Pollution
- Recycling of waste for economic and environmental purposes
- Increase and develop agricultural and Industrial Base for Egypt

Capstone Big Idea: Communication comes in many forms. One simple definition of communication is the exchanging of information, actions, signals, or processes. While we think about electronic and wireless electromagnetic communications between people, we can broadly think about biological, physical, and chemical communication systems within and between living organisms and other natural systems. Also we could think about it as the connection between different elements of any agricultural/industrial process and how changing one element could affect the whole process.

Essential Question: How does an understanding of biological, physical, chemical, and agricultural/industrial systems for transferring information (communications) lead to solving problems?

Design Challenge: Public health improvement is one the most crucial grand challenges that face Egypt. There are many interconnections between the level of public health problems and other grand challenges such as Pollution, recycling, and industrial/agricultural improvement.

Your main objective should be providing a solution to one of the public health related problems. You should Select one or more of Egypt's Grand Challenges as from mentioned (no additional points are given for having addressing more than one Grand Challenge). Identify one or more problems to address (no additional points are given for addressing more than one problem). Select a problem or a prior solution that contains the theme of communication in biological, physical, chemical, or agricultural/industrial systems as defined in the Big Idea. Identify design requirements for a successful solution to the problem, then select a small set of those design requirements to develop a testable prototype within the financial, time and resource constraints of your semester.

You may address a problem that is connected with different grand challenges (e.g. Recycling/Pollution/Public health problems, or Recycling/Improving Agricultural and or industrial base/public health problems…etc.)

You should provide a recommendation that connects your prototype' test plan results to the real-world problem.