Design-Based Online Teacher Professional Development to Introduce Integration of STEM in Pakistan

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Dedication

This work is dedicated with love and gratitude to my:

1. Dearest parents: Chaudhry Ghulam Rasul and Shamim Akhtar,
2. Loving husband, Anwar-ul-Haq Chaudhry,
3. Adorable daughters, Amna, Fatima and Khadija.

Abstract

In today's global society where innovations spread rapidly, the escalating focus on science, technology, engineering and mathematics (STEM) has quickly intensified in the United States, East Asia and much of Western Europe. Our ever-changing, increasingly global society faces many multidisciplinary problems, and many of the solutions require the integration of multiple science, technology, engineering, and mathematics (STEM) concepts. Thus, there is a critical need to explore the integration of STEM subjects in international education contexts. This dissertation study examined the exploration of integration of STEM in the unique context of Pakistan.

This study used three-phase design-based methodological framework derived from McKenney and Reeves (2012) to explore the development of a STEM focused online teacher professional development (oTPD-STEM) and to identify the design features that facilitate teacher learning. The oTPD-STEM program was designed to facilitate eight Pakistani elementary school teachers' exploration of the new idea of STEM integration through both practical and theoretical considerations.

This design-based study employed inductive analysis (Strauss and Corbin, 1998) to analyze multiple data sources of interviews, STEM perception responses, reflective learning team conversations, pre-post surveys and artifacts produced in oTPD-STEM. Findings of this study are presented as: (1) design-based decisions for oTPD-STEM, and

(2) evolution in understanding of STEM by sharing participant teachers’ STEM model for Pakistani context. This study advocates for the potential of school-wide oTPD for interdisciplinary collaboration through support for learner-centered practices.

Table of Contents

List of Tables

List of Figures

Chapter I: Introduction

In today's global society where innovations spread rapidly, the escalating focus on science, technology, engineering, and mathematics (STEM) has quickly intensified in the United States, East Asia, and much of Western Europe. Our ever-changing, increasingly global society faces many multidisciplinary problems, and many of the solutions require the integration of multiple science, technology, engineering, and mathematics (STEM) concepts. Thus, there is a critical need to explore the integration of STEM subjects in international education contexts. "Universal STEM acquisition," a recent term coined in a report on STEM: Country comparisons (Marginson, Tytler, Freeman, and Roberts, 2013, pg.68), reflects the ubiquitous role of science, technology, engineering, and mathematics education internationally and creates a sense of urgency to address STEM issues in international contexts where the conversations on STEM education are just beginning.

Rationale

Sahlberg (2006) argued that globalization is a cultural paradox that simultaneously unifies and diversifies nations and cultures through global education reforms. Core features of successful education systems around the world are becoming visible due to international comparisons of student achievement resulting in collaboration, idea sharing, and transfer of education policies. Pakistan is no exception to the impact of global education reforms.

Pakistan is a developing nation that is challenged by many internal and external factors contributing to a state of instability. The country also faces many stark questions about the ever-increasing need to update its education system, and in particular science education. According to Memon, Joubish, and Khurram (2010), the quality of elementary and high school education has continually declined in Pakistan, and science education, in particular, needs urgent improvement. Memon et al. (2010) attributed the deteriorating education system in Pakistan to factors such as low budgetary allocation for education, low qualifications of elementary teachers, low quality of teacher certification and teacher support, lack of meaningful and relevant content of education, and inadequate education research. Given these challenges, science education in Pakistan needs to draw on possible lessons and ideas that have proven to be of value elsewhere, such as the recent innovation of STEM integration (Marginson et al., 2013; Moore & Smith, 2014) which may have potential lessons for the Pakistani context.

Efforts to integrate across the STEM disciplines originated in the United States with the recognition of the value of STEM integration going beyond just mathematics and science (National Academy of Engineering and National Research Council (NRC), 2014). Two new transformational documents have taken the forefront in U.S. science education: *A Framework for K-12 Science Education* (NRC, 2012) and the resulting *Next*

Generation Science Standards (NGSS) (NGSS Lead States, 2013). Both documents aim to provide a new structural organization for science education that includes engineering practices. NGSS calls for science teachers to integrate science and engineering practices. Such integration will allow students to build, deepen, and apply their knowledge of core ideas of the physical sciences, life sciences, earth and space sciences, engineering, and technology.

This integration of science and engineering practices presents new opportunities and challenges for teachers, as they must now design learning experiences that include the work of engineers. Given the complexities of STEM integration, there is a pressing need to provide teacher professional development (TPD) programs focused on STEM integration. Desimone (2009), in particular, has recognized professional development as a key to reform in teaching and learning and a means to introduce, practice, and implement education reforms in classrooms. Other researchers, including Loucks-Horsley, Hewson, Love, and Stiles (1998) and Putnam and Borko (2000), have also suggested that reform-oriented professional development tends to be more effective than traditional professional development. These scholars especially highlight the need for more in-depth engagement at the beginning of a reform initiative. Studies have also shown that supporting teachers to prepare for new classroom practices allows for the translation of teacher learning into practice (Darling-Hammond & McLaughlin, 1995; Penuel, Fishman, Yatmaguchi & Gallagher, 2007).

With the growing emphasis on STEM integration, combined with the challenges of funding constraints, broad accessibility to TPD through online teacher professional development (oTPD) provides a promising vehicle for TPD (Ginsburg, Gray, & Levin, 2004). Given the rapid growth and access of the Internet all over the world, oTPD also provides the opportunity for global oTPD. One recent study noted that oTPD "fits the busy schedules, draws upon powerful resources often not available locally, and provides real-time, ongoing work-embedded support" (Whitehouse, Breit, McCloskey, Ketelhut, & Dede, 2006, p.13). oTPD offers various advantages including high quality learning opportunities, access to experts at low costs to districts, access to a video-based multimedia repository, reflection time prior to interaction, flexibility for teachers who have busy lives, and personalized learning spaces (Dede, Ketelhut, Whitehouse, Breit & Mckloskey, 2009; Sprague, 2006). Another advantage is that oTPD can mirror the distinguishing features of face-to-face teacher professional development with the added benefits of online TPD (Russell, Kleiman, Carey & Douglas, 2009).

Purpose of the Study

The purpose of this study was to design and test an online teacher professional development program to introduce integrated STEM (oTPD-STEM) in Pakistan. This study used design-based research to explore the development of this STEM-focused online learning environment and to identify the design features that facilitate teacher learning. The oTPD-STEM program was designed to facilitate Pakistani elementary school teachers' exploration of the new idea of STEM integration through both practical and theoretical considerations. This program was designed to support teachers for both pedagogy and content, addressing the challenges that are common to educational innovations such as providing teachers with pedagogical tools to facilitate learning for their students, while also connecting instructional decisions to science and mathematics content. The STEM integration model developed by Moore, Stohlmann, Wang, Tank, Glancy and Roehrig (2014) guided this study. The framework, which is described in detail in Chapter II, includes six key elements: (1) a motivating and engaging context, (2) the inclusion of mathematics and/or science content, (3) student-centered pedagogies, (4) an engineering design challenge, (5) learning from failure, and (6) an emphasis on teamwork and communication.

This exploration of oTPD-STEM through design-based research was completed with the goals of introducing teachers to the key elements of integration of STEM to construct a local theory and to design a framework for oTPD-STEM (McKenney & Reeves, 2012). The research goals also aimed to investigate the core design features of oTPD-STEM to facilitate teachers' understanding of STEM. This exploratory study first illustrates the evolution of design-based oTPD-STEM (see Chapter III) and then shares a case of a team of three participant teachers by describing their collaborative team interactions throughout the oTPD-STEM program (see Chapter IV). Finally, it describes the participant teachers' understanding of STEM by presenting their shared STEM integration model (see Chapter IV).

The purpose of this dissertation was to (1) identify oTPD-STEM design elements associated with supporting STEM-specific professional development in a Pakistani context; (2) recognize the evolution of Pakistani teachers' ideas of integration of STEM throughout their participation in the oTPD-STEM program, and (3) explore ways in which Pakistani participant teachers developed their understanding of integration of STEM.

Research Questions

The guiding research questions for this study were

1. What instructional design components make an effective online professional development program to support teachers' understanding of STEM integration?
2. How do Pakistani teachers' views of integration of STEM evolve throughout their participation in the oTPD-STEM program?
3. How do teachers explore the idea of STEM integration through their participation in an online teacher professional development program?

Significance of the Study

The increased emphasis on STEM education reform in developed nations and emerging developing nations is a call for immediate action to improve teaching and learning of STEM to meet the present and future needs of the world. However, existing international research on STEM education lacks sufficient details about STEM models, curriculum, and program implementation, the extent of integration of disciplines, the ways the integration STEM efforts are supported, and the resulting student learning outcomes (English, 2015; Marginson et al., 2013; Ritz and Fan, 2014). This study addresses this need through the exploration of a STEM-specific, design-based oTPD program that provides in-depth detail of the design decisions for adapting a theoretically grounded program to the pragmatic and local needs of Pakistani participant teachers. This study also shares the STEM conception models of Pakistani teachers whose understanding evolved as they wrestled with how to integrate STEM into their own local context. This new understanding will inform future work in Pakistan.

This dissertation study explores STEM integration in a Pakistani context and builds on the existing oTPD research in several ways. First, such research should produce "usable knowledge" (Dede at al., 2009) about salient instructional design components of oTPD-STEM that allow Pakistani teachers to explore and understand the integration of STEM. Second, using Kennedy's (2016) theory of action, this study illustrates how participant teachers' conceptions of STEM integration evolved as they learned, implemented, and reflected on STEM instruction. This relationship of (1) teacher conceptions of STEM, (2) ways teachers explored STEM, and (3) teacher-reported student responses supported by Kennedy's (2016) theory of action represents a subset of

Desimone's (2009) core conceptual framework that connects how PD improves teachers' instruction (theory of change) and how teacher's newly learned instruction allows for student learning (theory of instruction). Finally, this dissertation study affirms that allowing teachers to explore an innovative reform idea, such as STEM integration as a community of practice (Lave and Wagner, 1991) and by engaging in collaborative reflective practices (Brookfield 2005; Schön, 1983) can support the development of participant teachers' understanding of STEM within a context-specific setting.

Dissertation Overview

The following four chapters provide more details about the supporting literature, methodology, and findings related to the implementation of oTPD STEM in Pakistan. Chapter II further explores the rationale for the study and provides a detailed overview of the literature that grounded the oTPD-STEM program. In addition, this chapter presents the theoretical framework for the study. Chapter III describes the design-based research (DBR) approach to the design and exploration of oTPD STEM. Using this DBR approach, research question 1 is answered through a discussion of the evolution of oTPD-STEM experiences of eight Pakistani participant teachers. Chapter IV addresses research questions 2 and 3 through the presentation of the case of a team of three participant teachers. Finally, Chapter V includes a discussion of the findings, their implications, and suggestions for future research.

Chapter II: Literature Review

Since the Sputnik era, science education reforms have been at the forefront of education policy in the United States (American Association for the Advancement of Science [AAAS], (AAAS, 1989, 1993) (National Research Council [NRC], 1996, 2000). The recent focus on science, technology, engineering, and mathematics (STEM) education reform is an outcome of recent science education reforms (Next Generation Science Standards [NGSS] NGSS Lead States, 2013) and has gained momentum in the U.S., as well as internationally (English, 2015; Williams, 2011). In particular, developed nations like the United States, United Kingdom, Australia, Canada, Finland, and Switzerland have invested heavily in STEM education reform. The driving forces behind the global STEM education initiatives are mainly achieving vocational and economic goals (Williams, 2011). The vocational goals point to the skill shortage among employees in science and engineering areas, while the economic goals build upon the vocational rationale for adopting STEM to strengthen the workforce of tomorrow. Another significant goal for STEM education is improving students' 21st century skills like adaptability, complex communication, non-routine problem solving, and systems thinking to develop a STEM literate citizenry (Bybee, 2010).

STEM education has the potential to reform education and to globally contribute towards the goals of developing STEM literate citizens and vocational and economic goals. Thus, this study aims to investigate the potential of STEM integration in schools by helping participant teachers develop and implement a shared understanding of STEM integration, leading to a possible adapted STEM model for the Pakistani context. To explore STEM integration in a Pakistani context, the following literature review draws on research on STEM education reform from both U.S. and international contexts. The first section explores the definitions of STEM integration and existing STEM frameworks that guide K-12 implementation. The second section explores the professional development literature and presents professional development as a means to implement proposed STEM reforms. The third section presents literature supporting STEM-focused online teacher professional development. It also develops arguments and presents designs that are specific to online teacher professional development as incorporated in this study. Finally, the theoretical and conceptual frameworks for developing a design-based, online teacher professional development is presented.

Integration of STEM-Lessons from Past and Future Prospects

Origin of Integration of STEM

Interdisciplinary education dates back to the progressive education movement in the 1930s, initiated by Dewey who promoted the restructuring of schools to meet the needs of individual students (i.e., child-centered, hands-on experiences) to build an efficient society. More recently, socio-cognitive research has forwarded the specific agenda of integrated STEM education (National Research Council [NRC], 2000), but historical precedents for merging STEM disciplines can be found prior to recent STEM education reforms (Czerniak and Johnson, 2007). Some examples include the Science, Technology and Society (STS) movement based on Yager's (1983, 1984 & 1985) conceptions of science education.

The term STEM was introduced in 2001 when Judith Ramaley, then director of the National Science Foundation (NSF), rebranded a slightly older acronym SMET that dates back to 1993 (Donahoe, 2013). However, STEM remains an ambiguous term with no agreement on specified models of implementation (Bybee, 2013). Adding letters to the acronym has further obscured the meaning of STEM. STEAM (addition of arts), STREAM (addition of robotics and arts), STEM+H (addition of health sciences), and STEM+C (addition of computing) are a few of the existing variations of STEM (Portz, 2015). While the NSF-introduced acronym STEM has grown in popularity, the explicit operationalization of STEM has been left up to stakeholder interpretation.

STEM has flourished in distinct ways in different parts of the world. At its point of origin in the U.S., STEM emerged as "political reactionism to the political disposition of the US's global superiority" whereas in the UK, STEM has been envisioned as human capital (Blackley & Howell, 2015 p.102). However, Asian countries (e.g., China, Japan) with their high performing education systems and growing economies have broadly emphasized science and technology in their curriculums including both university and industry driven research and development. Initially, STEM was enacted in schools as

S.T.E.M. by “silo-ing” the four disciplines as “an artifact of history” (Moore & Smith, 2014. p. 7). However, since engineering is not considered a subject area in the curriculum of either primary or secondary schools (Bybee, 2010) and there are conflicting interpretations of “technology” (Williams, 2011), the focus of STEM has shifted towards S.t.e.M, meaning continued teaching of science and mathematics while ignoring engineering and technology. This hazy context has led the education community to subvert the political agenda behind STEM by viewing the interplay of the four disciplines in STEM education as an urgent educational initiative. With the recent introduction of the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013), based on a Framework for K-12 Science Education (NRC, 2012b), engineering design has more recently been included alongside physical science, life science, earth science, and space science; thus, elementary and secondary science teachers are required to consider and develop approaches to integrate engineering into their science instruction.

Currently in the U.S., the Framework for K-12 Science Education (NRC, 2012a) and the resulting Next Generation Science Standards (NGSS Lead States, 2013) guide the policy and implementation of integrated STEM in K-12 classrooms. These documents suggest a new structural organization for science education that now includes both technology and engineering practices. The integration of science and engineering practices presents new opportunities and challenges for teachers as they must design new, integrated learning experiences. Although engineering acts as a motivator for integration of STEM, effectively integrating engineering and science is a challenge (Guzey, Moore, & Harwell. 2016). With the inclusion of practices, crosscutting concepts, and disciplinary core ideas in NGSS, there is a continued need to understand how integration of STEM works in classrooms, and large-scale assessments become more essential (Moore & Smith, 2014).

Purpose of Integration of STEM

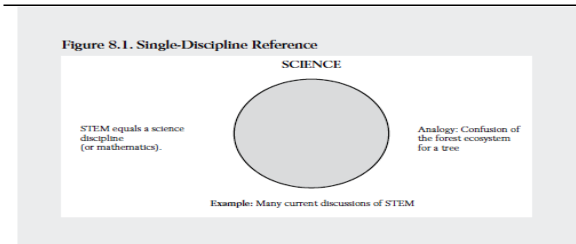
The push for integrated STEM education comes from economic and social equity arguments. The economic rationale argues for increasing advanced training and careers in STEM fields to expand the STEM-capable workforce, while the social equity rationale advocates for improving scientific literacy for all students (NRC, 2011). Together, this rationale supports the continually growing demand for the required STEM skills to meet present and future global economic and social challenges (English, 2016; NRC, 2014). Similarly, Zollman (2012) described the purpose of STEM integration for resolving (1) societal needs for new technological and scientific advances; (2) economic needs for national security; and (3) personal needs to become a fulfilled, productive, and knowledgeable citizen. To view STEM education reform distinctly from other education reform efforts, it is important to understand three key goals: (1) a response to global economic challenges, (2) recognition of the demand for STEM literacy for solving global technological and environmental problems, and (3) a focus on the knowledge needed to develop 21st century workforce skills (Bybee, 2013).

Bybee (2013) clearly articulated that the overarching goal of STEM education reform is to develop a STEM-literate society. According to Bybee, STEM literacy requires individuals to (1) develop knowledge, skills, and attitudes to identify, explain, and address real-world problems; (2) understand characteristic features of STEM disciplines; (3) recognize how STEM disciplines shape material, intellectual, and cultural environments; and (4) engage in STEM issues as a reflective, global citizen.

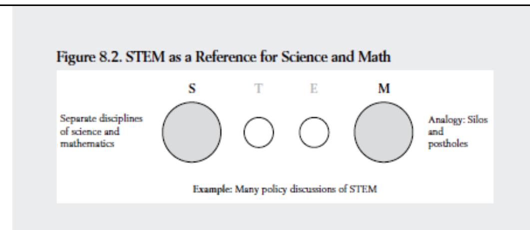
Calls for improving the teaching of science and mathematics in schools have accelerated these needs due to a decline in American students' competitiveness with other countries in STEM fields, placing only 17^{th} in science and 25^{th} in mathematics achievement. Ultimately, a broader goal underlying the STEM movement to increase "STEM literacy" takes the forefront to create more interest in STEM disciplines, to raise student performance in STEM disciplines, and to increase access to the STEM workforce pipeline. However, STEM literacy goes beyond a traditional discipline-bound view of science, technology, engineering, and mathematics. It also focuses on the use and application of that knowledge to local, national, and global contexts. Furthermore, STEM literacy includes the development of 21^{st} century skills and abilities of adaptability, complex communication, non-routine problem solving, self-management, and systems thinking (Bybee, 2013).

Perspectives on Integration of STEM

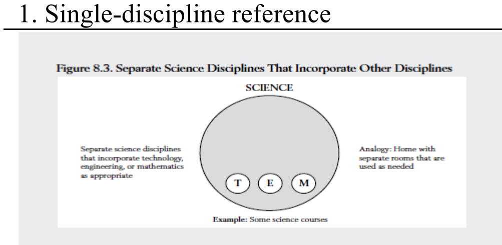
Integration can take place in a variety of ways based on the various approaches of de-compartmentalizing content across subject areas to promote relevance through real-world problems. Bybee (2013) described the unique characteristics of nine common approaches to STEM, while asserting that no one approach is the best (see Figure 2.1).



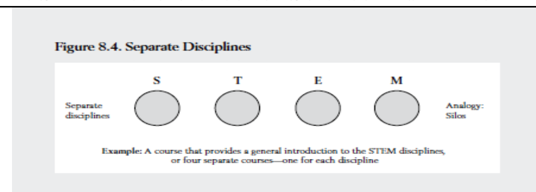
1. Single-discipline reference



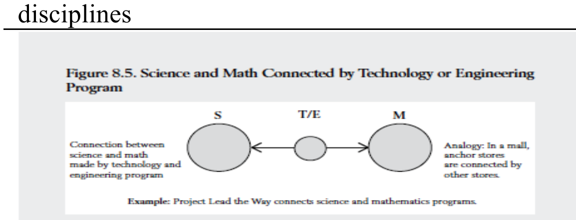
2. STEM as reference for Science and Mathematics



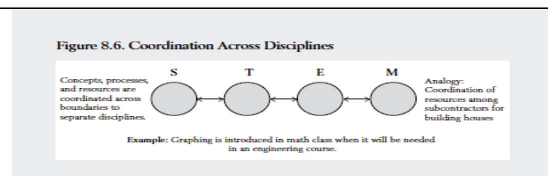
3. Separate Science disciplines that incorporate other disciplines



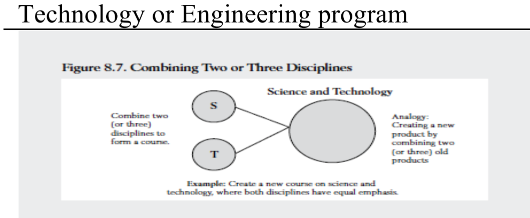
4. Separate disciplines



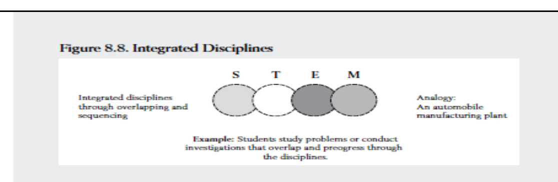
5. Science and Mathematics connected by Technology or Engineering program



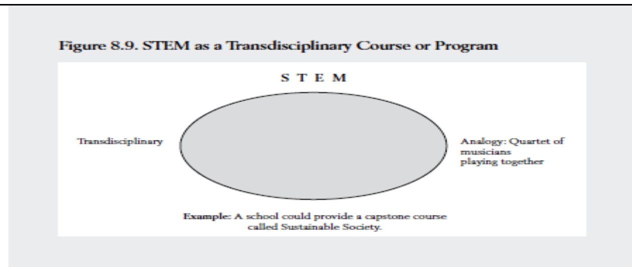
6. Coordination across disciplines



7. Combining two or three disciplines



8. Integrated disciplines



9. STEM as a transdisciplinary course or program

Figure 2.1. Nine different models of STEM. Reprinted from *The Case for STEM Education: Challenges and Opportunities* (p. 74-79), by R. W. Bybee, 2013, Virginia: NSTA. Copyright 2013 by the National Science Teachers Association. Reprinted with permission.

Bybee's (2013) first model simply represented STEM as a proxy for a single discipline, e.g., science or mathematics. His model is common in the international literature on STEM and usually appears when the emphasis is on developing science education. The second model of STEM refers to science and mathematics as traditional school subjects in their separate siloes. The third STEM model shows science as the main discipline that incorporates technology, engineering, and mathematics, which, according to Bybee (2013), is the first step towards integration. The fourth STEM model is referred to as a quartet of four separate disciplines, again highlighting the norm in U.S. schools to silo the disciplines. The fifth STEM model presents science and mathematics as stand-alone disciplines with connections to another program that emphasizes technology and/or engineering. A common example of this perspective is the use of technology and engineering projects to connect core subjects of science and mathematics to experiences in professional and technical education. The sixth STEM model represents coordination across disciplines. The seventh STEM model represents the combination of any two or three disciplines that result in a new complex STEM course. The eighth model of STEM integration seeks complimentary overlap across the disciplines, where the disciplines are integrated by sequencing lessons, units, or courses. The final STEM model represents a transdisciplinary approach used to address global grand challenges.

In contrast to Bybee's nine models, Vasquez, Sneider and Comer (2013) described STEM teaching and learning as an inclined plane that has increasing levels of integration (see Figure 2.2). At the lowest end of the inclined plane sits the disciplinary approach to teaching where content and skills of the different subjects are taught in separate classes. This disciplinary approach is similar to Bybee's second and fourth models that represent two or all four STEM disciplines in silos. Moving up the inclined plane is the multidisciplinary approach. This approach draws on knowledge from across the STEM disciplines but each discipline stays within its boundaries in reference to a common theme. This is parallel to Bybee's third, fifth, and sixth models. Moving further up the incline is interdisciplinary integration of STEM. This approach analyzes, synthesizes, and harmonizes links between disciplines into a coordinated and coherent whole, similar to Bybee's seventh and eighth STEM models. At the top of the inclined plane is transdisciplinary integration, similar to Bybee's ninth model. Unlike the traditional disciplinary approaches, Vasquez (2014/2015) argued that there is value in both multidisciplinary and interdisciplinary STEM integration. Moving towards the most highly integrated STEM approach, Vasquez noted that the transdisciplinary approach often takes “a small step” (p.14) from the multidisciplinary or interdisciplinary approaches.

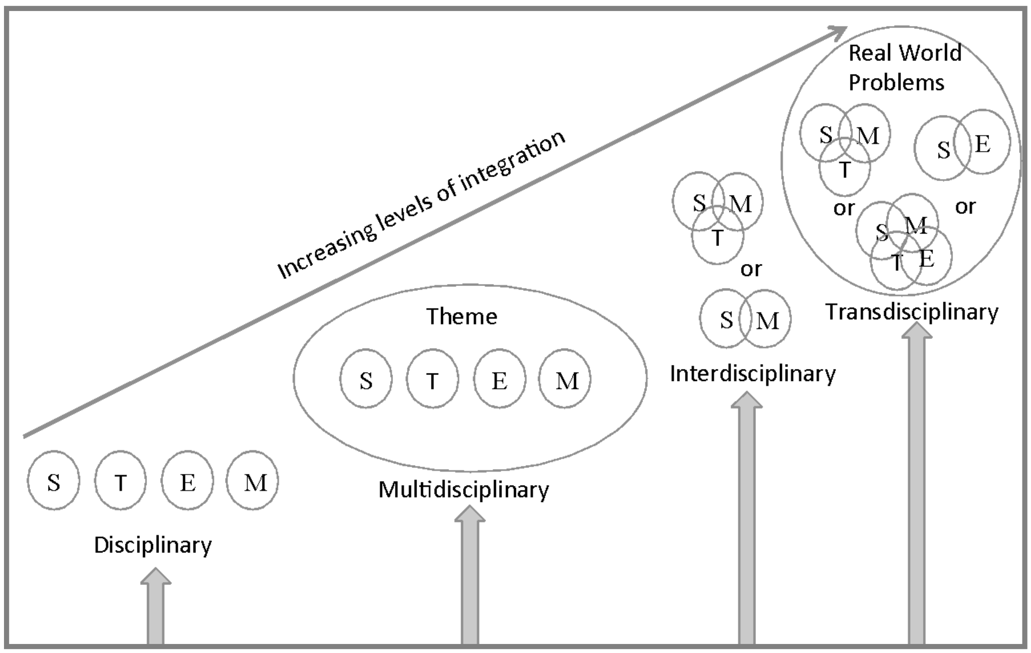


Figure 2.2. The inclined plane of STEM integration. Adapted from *STEM Lesson Essential, Grade 3-8: Integrating Science, Technology, Engineering and Mathematics* (p. 73), by J. A. Vasquez, C. Snelder, and M. Corner, 2013, New York: Heinemann. Copyright 2013 by authors.

Sander (2009) suggested another framework for teaching STEM based on integrating two or more STEM subjects and also included the flexibility to involve non-STEM subjects (see Figure 2.3). Sander’s (2009) STEM integration framework conforms to the interdisciplinary approach of Vasquez et al. (2013) and also illustrates what Bybee described as the eighth model of integrated disciplines.

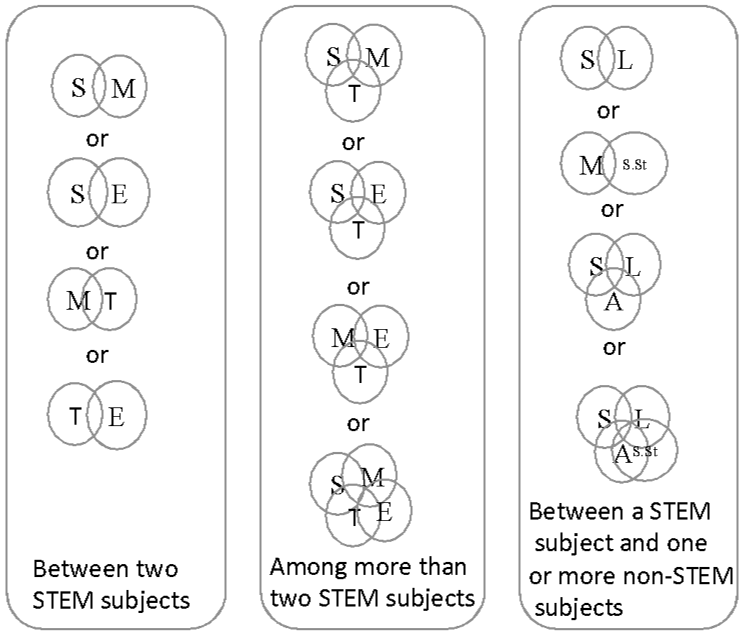


Figure 2.3 Sander's (2009) STEM integration framework.

Juxtaposed to Sander's (2009) description of STEM education that argued for connecting two or more of the disciplines, Merrill (2009) proposed that "STEM teaching and learning focuses on authentic content and problems, using hands-on, technological tools, equipment, and procedures in innovative ways to help solve human wants and needs." Similarly, Brown, Brown, Reardon, and Merrill (2011) explained integration of STEM as follows:

> A standards- based, meta-discipline residing at the school level where all teachers, especially science, technology, engineering, and mathematics (STEM) teachers, teach an integrated approach to teaching and learning, where discipline

specific content is not divided, but addressed and treated as one dynamic, fluid study (p.6).

Merrill's (2009) and Brown et al.'s (2011) STEM model aligns with Vasquez et al.'s (2013) transdisciplinary approach. Recent studies have furthered our understanding of the integration of STEM. Moving from generic to specific descriptions of STEM integration, Moore and Smith (2014) refined Sander's (2009) work by explaining integration of STEM in two ways: (1) context integration where engineering design acts as a motivator for learning mathematics and science content, and (2) content integration where the content of mathematics and science along with engineering are part of the learning objectives (see Figure 2.4). Moore and Smith's (2014) content integration aligns with Vasquez et al.'s (2013) interdisciplinary approach whereas content integration represents a transdisciplinary approach.

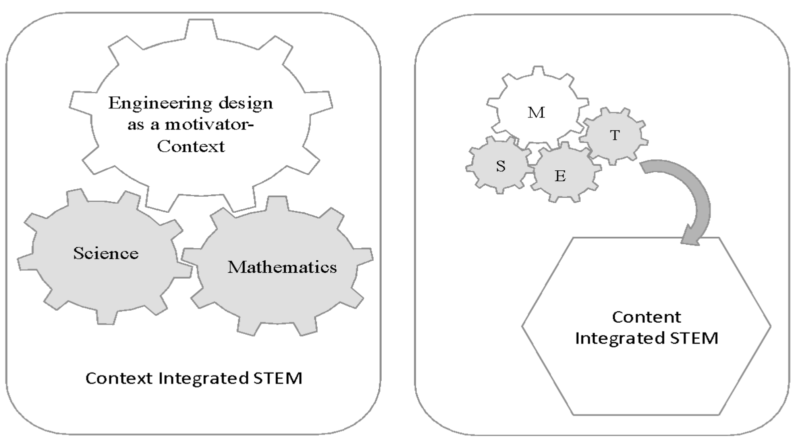


Figure 2.4. Moore et al., 2014's context integration and content integration

Moore, Stohlmann, Wang, Tank, Glancy, and Roehrig (2014) developed a framework for STEM integration that includes six key elements: (1) a motivating and engaging context, (2) the inclusion of mathematics and/or science content, (3) student-centered pedagogies, (4) an engineering design challenge, and (5) learning from failure, and (6) an emphasis on teamwork and communication. Using this framework, science and/or mathematics content or content from all four disciplines of STEM could be emphasized. This framework explains STEM integration as "an effort by educators to have students participate in engineering design as a means to develop technologies that require meaningful learning and an application of mathematics and /or science" (p.38). This approach uses six key elements to create meaningful connections among the four STEM disciplines. The context of a STEM-integrated curriculum needs to involve a purposeful and motivating local issue/challenge that could allow students to apply an engineering design process in a completely or partially realistic situation. The STEM-integrated curriculum needs to allow students to understand and use science and/or mathematics content while addressing the issue using engineering design challenges. Engineering design challenges engage students to help them explore, design, test, and redesign so students can learn from failure. Most significantly, this framework emphasizes the use of student-centered pedagogies to implement STEM-integrated lessons and teamwork. Communication remains at the core of this approach by engaging students who are working in teams to solve the engineering design challenge. The accompanying science and mathematics activities also encourage students to communicate how they designed technologies under the constraints, safety, risks, and alternative solutions. Moore et al.'s (2014) framework for quality STEM education was also used in oTPD-STEM to introduce integration of STEM to the Pakistani participant teachers in the current study.

Challenges in Implementation of Integration of STEM

While integration of STEM presents promising solutions to pressing global problems, this instructional approach is still ambiguous, and effective implementation of STEM integration needs to be explored further (Breiner, Harkness, Johnson & Koehler, 2012). There is empirical support for the positive impact of STEM integration on teaching and learning (Burghardt & Hacker, 2007; Stohlmann, Moore, McClelland & Roehrig, 2011). The existing emphasis on integration of STEM is based on research and focuses on the impact on students. Some studies claim that integration of STEM increases students' interest (Brusic, 1991; Ingram, 1966) and problem solving skills (Loepp, 1999; Schafer, Sullvian, & Yowell, 2003), and other studies claim that it increases achievement among certain underrepresented student groups (Mehalik, Doppelet & Schunn, 2005), and decreases behavioral problems (Cordogan, 2001). However, high quality implementation of STEM integration in K-12 classrooms is not common (Nathan, Tran, Phelps, & Prevost, 2008; Prevost, Nathan, Stein, Tran, & Phelps, 2009). Additionally, K-12 teacher expertise across the individual STEM subjects is often lower than what professional organizations in the field recommend (Honey, Pearson, & Schweingruber, 2014). Thus, the question remains as to what extent a teacher must have expertise in multiple STEM content areas (National Research Council NRC, 2014). Stinson, Harkness, Meyer, and Stallworth, (2009) have found that teachers have gaps in their subject content knowledge and suggest that asking mathematics and science teachers to incorporate another subject may create new knowledge gaps and challenges.

Yet another challenge to integrating STEM is ensuring coherent learning outcomes of STEM integration. It is still unclear whether integration of STEM contributes to improved and deeper conceptual learning (Guzey et al., 2016). Existing research shows ample examples of how students construct a coherent disciplinary knowledge base but examples of an interdisciplinary or transdisciplinary knowledge base are still limited (NAE & NRC, 2014). This calls for further research about the curricular designs and instructional plans that could generate knowledge from the four STEM disciplines to yield coherent learning. A possible reason for this challenge is the prevailing inconsistency in approaches and pedagogies. Another aspect of this challenge is the difficulty of assessing student learning in multiple disciplines. In particular, NGSS (NGSS Lead States, 2013) has highlighted the issue of the ineffectiveness of commonly used assessments like quizzes and exams in reporting students' learning of STEM.

STEM in International Contexts

Increasing globalization has serious repercussions for education (Stromquist & Monkman, 2014). Ideas used in the global market (e.g., efficiency and productivity) have been extended to schools shifting the focus from person-centered skills to work-preparation skills. Education is becoming another marketable commodity instead of a public good. Another impact of globalization is the comparative study of educational outcomes across and within countries. This emphasis on international measurement and comparison of student outcomes has been pushed by international organizations such as the International Association of Evaluation of Educational Achievement which produces Trends in International Mathematics and Science Study (TIMSS), the Organization for Economic Cooperation and Development (OECD) that runs the Program for International Student Assessment (PISA), the World Bank, the Inter-American Bank, the Asian Development Bank, non-governmental organizations (NGOs) such as Inter-American Dialogue, and bilateral agencies such as the U.S. Agency for International Development (USAID). All of these organizations share a globalized view of education and efficiency.

The prominence of STEM education in the US and the UK is significant because other countries tend to follow their lead. Some European and Asian countries tend to follow the US, while the Commonwealth countries tend to follow the UK. The Australian Council of Learned Academies shared their final report on International Comparisons of Science, Technology, Engineering and Mathematics (STEM) Education, (2013), stating that countries strong in STEM are diverse in their economies, political and social cultures, and in their educational traditions, so certain features are common among these countries. In their report Marginson, Tytler, Freeman, and Roberts, (2013) stated,

> Most nations are closely focused on advancing STEM, and some have evolved dynamic, potent and productive strategies. In world terms Australia is positioned not far below the top group, but lacks the national urgency found in the United States, East Asia and much of Western Europe, and runs the risk of being left behind (p.10).

Internationally, different models of STEM education exist because of the unique political, cultural, and economic conditions of countries around the world. Some countries have explored science and mathematics integration, while in other countries, technology has been added to science and mathematics, and some countries have focused heavily on integration of STEM. Recently, English (2015) argued for a greater focus on STEM integration, with equitable representation of STEM disciplines while recognizing the complexity of STEM integration within and across nations.

One of the key challenges to a common approach is that existing international research on STEM education lacks sufficient details about STEM models, curriculum, and program implementation, the extent of integration of disciplines, ways the efforts for integration of STEM are supported, and the resulting student learning outcomes. English (2015), Marginson et al. (2013), and Ritz and Fan (2014) have all documented the trends and challenges of STEM education in the international context, which has opened up new directions and possibilities in STEM research endeavors. This dissertation study adds to this call by exploring the ways teachers understand STEM integration and visualize their context-specific STEM model.

With the growing focus on STEM, trends in the interpretations of STEM are becoming common. Ritz and Fan (2014) identified that the Netherlands and South Korea are working to implement solely integrative STEM knowledge-based programs, which is what Vasquez et al., (2013) described as a transdisciplinary approach to STEM integration. England, Ireland and Japan have also attempted to enhance the integration of science, technology, engineering and mathematics in education, which also closely resembles Vasquez et al.'s (2013) multidisciplinary approach. Ritz and Fan (2014) also noted that the majority of countries like Australia, Belgium, Canada, China, India, Scotland, and South Africa are exploring both options of integrative STEM and the improvement of the stand-alone individual subjects. The presence of such varied perspectives of STEM is very common in the United States as well (Bybee, 2013).

English (2015) discussed the danger that science will overshadow the importance of mathematics since the STEM acronym is still referred to as "science" (Office of the Chief Scientist, 2014). This problem can be viewed by looking at the first model where Bybee, (2013) described STEM as a proxy for a single discipline, and most often that single discipline is science and it neglects the remaining disciplines in STEM. These issues cause inequitable representation of STEM disciplines, which is also highlighted in the international literature on STEM integration (English and Krishner, 2016; Honey et al., 2014).

Integration of STEM in the Specific Context of Pakistan

Since the inception of Pakistan in 1947, the socio-political situation has never allowed a focus beyond basic educational needs. This is evident through the Education for All (EFA) goals and the post-2015 agenda for education in Pakistan (Education for All National Review Report: Pakistan, 2015). Pakistan is still struggling to provide equitable access to education at all school levels (Aziz, Bloom, Humair, Jimenez, Rosenberg, Sathar, 2014). According to Memon, Joubish, and Khurram (2010), the quality of elementary and high school education is continually declining and science education needs urgent improvement. Memon et al. (2010) attributed this deteriorating education system in Pakistan to factors such as low budgetary allocation for education, low qualifications of elementary teachers, low quality of teacher certification and teacher support, lack of meaningful and relevant content of education, and inadequate research on education.

As a developing country that is continually exposed to a plethora of economic, governance, and security challenges (World Bank, 2016), Pakistan needs to transform its education system to address the pressing needs of its future citizens. STEM education reform offers potential empowerment to the youth of Pakistan by providing a pathway to the country's and global STEM workforce as well as by attaining STEM literacy to cope up with the ever-increasing issues of bad governance and security.

Role of Teacher Professional Development in Education Reform

For integration of STEM to occur, teachers need to extend their knowledge of science, technology, engineering, and mathematics, and learn new pedagogical skills that incorporate inquiry, reasoning, problem solving, and creativity (Marginson et al., 2013; Ritz and Fan, 2014). Implementing STEM integration will require new strategies such as team teaching and cross-curricular learning and practices which are difficult to sustain (Ritz and Fan, 2014). Currently, STEM education in international contexts requires refining the meaning of STEM, developing materials to support instruction and student learning, and most importantly, quality teacher professional development (Marginson et al., 2013; Ritz and Fan, 2014).

Reflecting on the history of teacher professional development (TPD), Cochran-Smith and Fries (2008) described the evolution of teacher professional development as moving from a curriculum problem (1920s-1950s) to a training problem (1960s-1980s) to a learning problem (1980s-2000s) to a policy problem (1990s-present). In recent years, considerable emphasis has been on the nexus between teacher learning and student learning, and teaching as a learning profession (Darling-Hammond and Sykes, 1999). Research on teacher professional development has substantially contributed to our understanding of how to best plan, implement, and evaluate TPD that is specific to integration of STEM. This research has also improved the quality and efficiency of TPD, yet much work is still needed.

Reform Oriented Teacher Professional Development

TPD is a complex venture (Hewson, 2007). TPD that facilitates teachers' understanding of educational reforms allows teachers to envision reform through enactment (Loucks-Horsley et al., 1998; Putnam & Borko, 2000). Similarly, Desimone (2009) suggested that professional development is a direct route to bring reforms into the classroom since it helps teachers translate research into practice ((Darling-Hammond & McLaughlin, 1995; Penuel, Fishman, Yatmaguchi & Gallagher 2007). However, Penuel et al. (2007) concluded that when PD providers adapt PD activities for specific groups, they must balance teachers' own contexts, the PD demands, and the need to negotiate the PD goals within the school and classroom.

Core Features of Effective Teacher Professional Development

Despite the emphasis on TPD to support teachers in enacting various education reforms, little is known about how teachers apply what they learn during TPD to their classroom practice (Hewson, 2007). Despite this relative lack of knowledge, the existing literature on TPD has collectively suggested five distinguishing features of effective TPD: (1) focus on content and classroom practice that involves subject matter and pedagogical knowledge, (2) active and inquiry based learning, (3) coherence in its goals and design, (4) duration and sustainability, and (5) collective learning (Desimone 2009; Desimone & Garet, 2015).

Content focus of TPD. Content focus within professional development is considered one of the most influential features for teacher learning (Desimone, 2009). Research suggests that when both content and pedagogy are included as part of PD, the intervention has a greater potential for a positive impact on student achievement than when PD is focused on content or pedagogy alone (Hill, Rowan, & Ball, 2005). Some studies have provided evidence of the nexus between TPD activities that focus on subject matter content and how students learn that content. These studies have shown an increase in teacher's pedagogical content knowledge that subsequently increases student learning (Cohen, 1990; Garet, Poter, Desimone, Birman & Yoon, 2001; Desimone 2009).

Active learning. This feature of effective TPD corresponds to the provision of opportunities for teachers to observe, receive feedback, analyze student work, or make presentations, unlike traditional TPD where teachers are passively listening to lectures (Garet at al., 2001; Loucks Horsely et al., 1998). Furthermore, professional development that includes time for instructional planning, enacting, discussion, and consideration for adapting curriculum may be more effective in supporting the implementation of innovative education reform initiatives (Penuel et al. 2007).

Coherence. Coherence describes how well the TPD is aligned with the teachers' and schools' perspectives in the areas of (1) the teachers' learning goals, knowledge, and beliefs; (2) the school curriculum and goals; and (3) the needs of the students and the school, district, and state reforms/policies (Fullan, 1993; Guskey, 2009; Penuel et al. 2007). When the teacher can see the alignment of TPD goals, personal goals, school goals, and reform goals, then it is easier for the teacher to buy into the ideas presented in TPD.

Duration and sustainability. Generally, teacher professional development programs are "fragmented, intellectually superficial" seminars (Borko, 2004, p.3). Many researchers have recommended making a shift from the one-time workshop to intensive, ongoing, and connected to practice (Desimore, 2009; Garet, Poter, Desimone, Birman & Yoon, 2001; Guskey & Yoon, 2009; Marrongelle, Sztajn, & Smith, 2013). A large-scale national study that sampled American mathematics and science teacher PD initiatives from 2004-2007 indicated that PD programs that appeared to change teachers' instructional practices were over 50 hours in length (Blank, De las Alas, & Smith, 2008). Supovitz and Turner (2000) suggested 80 hours of PD as the point at which PD begins to produce significant differences in self-reported teacher use of inquiry-based teaching practices and levels of investigative culture in the classroom. Some other studies have shown support for TPD activities that are spread over a semester or intense summer institute with follow up during the semester and spanning over 20 hours or more of contact time in total (Desimone, 2009).

Collective participation. This significant feature refers to professional development in which teachers participate together with colleagues from their school and district (Garet et al. 2001). Such collaboration creates interaction, discourse, and potential resources for teachers in support of their implementation. This concept is supported by research that reveals that reforms become powerful when stakeholders embrace the change (Desimone, 2009; Penuel et al. 2007).

Effects of Teacher Professional Development

Existing research on professional development uses theories of (teacher) change and theories of instruction to better understand how PD improves teaching and learning (Desimone, 2009; Fishman, Konstantopoulos, Kubitskey, Vath, Park, Johnson and Edelson, 2013; Wayne, Yoon, Zhu, Cronen and Garet, 2008). Desimone, (2009) and Fishman et al. (2013) have emphasized teacher learning from PD and have proposed the use of both theory of change and theory of instruction to better understand (1) how well the professional development activities elicit improvements in teacher knowledge and instruction (theory of change) and, (2) how the new content or pedagogy learned in professional development improves student learning (theory of instruction). Wayne et al. (2008) described the theory of change as related to how features of PD promote changes in teacher knowledge and/or practice and theory of instruction as providing links between the specific kinds of teacher knowledge and instruction emphasized in the PD and the expected changes in student achievement. Research supports using both theory of change and theory of instruction to completely understand how professional development works (Fishman et al, 2013, Cohen & Hill, 2000). Based on the existing research, Desimone (2009) proposed a core conceptual framework for studying TPD that illustrates the interactive relationships between the core design features of PD, teacher knowledge and beliefs, classroom practices, and student outcomes operating within a context (see Figure 2.5).

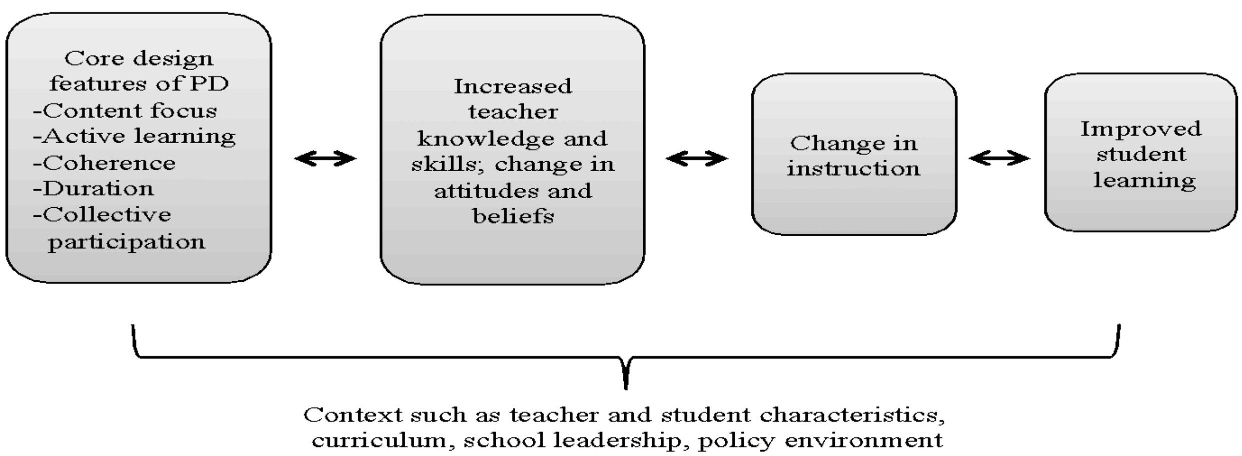


Figure 2.5. Core conceptual framework for studying the effects of teachers' PD. Adapted from Desimone (2009)

Desimone's (2009) core conceptual framework provides a powerful foundation for studying the effects of professional development on teachers and students that is warranted by theory and case study, correlational, and experimental research. Although

Desimone's (2009) framework serves as a foundation on which a coherent knowledge base could be built, it does not prevent the possibility of adapting, modifying, or extending the framework to reflect the specific goals of PD.

Kennedy (2016) has recently proposed the use of underlying "theories of action" to illuminate the PD's core purpose and premises about teaching and teacher learning. The theory of action maps out a specific pathway within the theory of change. Due to the lack of an overarching theory of teaching or of teacher learning, identifying underlying theories of action of PD programs first identifies a central problem of practice that the intervention aims to inform and then it devises pedagogy that will help teachers enact new ideas, translating them into the context of their own practice (Kennedy, 2016). Kennedy's PD theory of action takes a closer look at the problem of practice and pedagogy used to help teachers translate new ideas into their own system of practice. Kennedy's theory of action can be visualized by viewing it as embedded within the theory of change (Wayne et al., 2008) and, in turn, this theory of change is connected to the theory of instruction as Desimone's (2009) core conceptual framework.

Case for Online Teacher Professional Development: oTPD-STEM

Moving towards Online Teacher Professional Development

Recently, online teacher professional development (oTPD) has emerged as a solution to address the escalating need to prepare teachers for the challenges of STEM integration (Ginsburg, Gray, & Levin, 2004). Whitehouse et al. (2006, p.13) highlighted the significance of oTPD by featuring significant qualities such as “it fits their busy schedules,” and “it provides realtime, on-going work-embedded support.” Dede et al. (2009) also highlighted another, often neglected aspect of oTPD: it is a way to listen to the unheard voices of practitioners. oTPD can provide a safe environment for teachers to share insights about their everyday practices. It also has the potential to provide “just-in-time assistance” and can be more scalable than PD that presses on limited local resources (Wilson et al. 2013). Sawchuck (2009) also claimed that oTPD adds “continued, sustained engagement in content with peers” that will translate into changes in teacher behavior and improved student learning (p.2).

Online teacher professional development can mirror the distinguishing features of face-to-face teacher professional development with the added benefits of online TPD (Russell, Kleiman, Carey & Douglas, 2009). oTPD offers beneficial implications as opposed to its counterpart, traditional face-to-face PD. Some prominent benefits of oTPD include additional reflection time, implementation support, sustained interaction with peers, reduced cost, and opportunities for more reticent participants to contribute (Dede et al. 2009; National Staff Development Council, 2001). Another influential aspect of oTPD is that it promotes learning through reflection and communication (Bowman, Boyle, Greenstone, Herndon, & Valente, 2000).

Although research suggests that oTPD has the potential for “just-in-time assistance” and scalability, there is little evidence available to understand the affordances of online professional development (Dede et al. 2009). However, in their comparison study between online and face-to face TPD, Fishman et al. (2013) indicated that there is no significant difference between teachers' and students' learning gains in both conditions. Fishman et al. (2013) also asserted that there is a common tendency to treat online TPD as if it represents a particular approach rather than a delivery vehicle. The findings from the Prime Online oTPD program suggest that there are several benefits of well-designed and implemented oTPD that go beyond the convenience alone and move towards high-quality learning opportunities for impacting teachers' mathematics content, pedagogy, and student learning (Pape, Prosser, Griffin, Dana, Algina, & Bae, 2015). The findings from Fishman et al. (2013) encourage PD providers to design and plan oTPD for teachers who are challenged to integrate STEM along with the push to increase their discipline-specific expertise. They also urge science teacher educators to continue to close the existing gaps in the impact of PD on science teacher learning, practice, and student learning.

While there are several opportunities offered by oTPD, some concerns include lack of collegiality, lack of hands-on-experience, and questionable active learning experiences (King, 2002). oTPD does not require teachers to gather in one place, making oTPD accessible to geographically isolated teachers, but this might result in an inability to develop trust and collegiality among participants or serious constraints for providing active learning experiences (Fishman et al., 2013).

Although the research has shown promising benefits of oTPD, to date, the focus has mostly been on the characteristics of existing oTPD, and little has been done to examine the design and impact on the instructional practices of teachers and student learning (Ginsburg, Gray, & Levin, 2004; Whitehouse et al., 2006). Ginsberg et al. (2004) reviewed 40 oTPD programs to analyze these programs for effectiveness and quality and found none of these programs offered independently collected, objective evidence of better teaching or improved student outcomes. Ginsberg et al. (2004) also found that the oTPD programs lacked rigorous independent assessments of the impact on teacher or student outcomes; thus, there is a need for further research into oTPD programs.

Grounding for oTPD-STEM

Research clearly indicates that effective teacher professional development includes a content focus (Garet et al., 2001), collaborative learning environment (Darling-Hammond & McLaughlin, 1995), reflective practices (York-Barr et al., 2006) and ongoing support (Mizell, 2010), such as classroom coaching (Knight, 2009; Wong & Wong, 2008). However, STEM teacher professional development programs rarely implement these best practices (Wilson, Rozelle, & Mikeska, 2011). Wilson et al. (2011) attributed the inadequacies in professional learning opportunities to the lack of systemic teacher preparation, induction, and professional development programs. Professional learning opportunities are often selected on the basis of interest, taste, and convenience, or are mandated which results in an incoherent, diffuse, and uncoordinated system. Given the intense emphasis on STEM, the current literature (Marginson et al., 2013) calls for greater exploration of STEM-focused teacher professional development to contribute to administrators' understanding of how to convince teachers to buy into urgent education reforms in teacher professional development programs.

Goals of oTPD-STEM

Professional development goals for oTPD-STEM are aimed at inviting teachers to experience integration of STEM into their specific context and to initiate dialog about the integration of STEM in their school context. Although the PD goals are aligned with the overarching aim of this research study, the specific research goals are (1) to investigate the core design features of oTPD-STEM that facilitate teachers' understanding of STEM and (2) to explore ways in which Pakistani teachers developed and evolved their understanding of integration of STEM in an oTPD-STEM program.

Theoretical Frameworks

Two main theories guided this study: reflective practice and community of practice (situated learning). These theoretical frameworks hold a central position in conceptualizing the intervention and later informed the research design and analysis of the study.

Reflective practice. Reflective practice is widely recognized as a central component of the teaching and learning process (Brookfield, 1995, 2005). The usefulness of reflective practice has led to the idea of reflection which has been adopted as a foundation for many teacher education programs (Richert, 1990; Tom, 1985; Valli, 1993). Reflective practice is about thoughtful deliberation (Tickle, 1994) that not only enables teachers to link theory and practice but also helps them change and grow. A variety of frameworks for reflective practice exist (e.g. Schön, 1983; Kolb, 1984; Gibbs , 1988; Rolfe, 2001; Rodgers, 2002); however, there is general agreement that reflective practices are derived from the work of John Dewey. According to Dewey (1933), we begin to reflect on a complex situation when we face that situation and ask ourselves what needs to be done. Dewey stated that, "We do not learn from experience…we learn from reflecting on experience" (p.78), and that reflection should lead to action. Schön (1983) further developed Dewey's ideas and identified two types of reflection: reflection–on-action and reflection-in-action. In reflection-on-action, teachers review, describe, analyze, and evaluate their past practices with a goal of gaining insights to improve future practice. In contrast, during reflect-in-action, teachers examine and respond to events as they occur in real time. In both types of reflection, professionals seek to build new understanding to shape their action in an unfolding situation. Killion and Todnem (1991) added another category of reflection: "reflection-for-action" that occurs before beginning the task. Reflection-for-action provides for a deeper focus on lesson planning which is an especially important learning space for beginning teachers.

Learning is central to individual or organizational improvement involving not only student learning but also teacher learning. Learning is a result of processing experiences through reflection. As cited in Gramston and Wellman (1997), "Adults do not learn from experience, they learn from processing experience" (p.1). York-Barr, Sommers, Ghere and Montie (2006) also found great potential in reflective practices that help educators "stay challenged, effective, and alive in their work" (p.27).

Reflective practices are a distinguishing feature of adult learning. When adults encounter a learning situation, they immediately filter information based on their prior knowledge and experience. They identify similar and dissimilar patterns and apply cognitive processes for sense making. Adult learners continually move between new information and prior knowledge, and utilize their inquiry processes. Mezirow, an adult learning theorist, developed the transformative learning theory which describes transformative learning as incorporating the examination of assumptions, sharing ideas for insights, and taking action on individual and collective reflection. The role of reflective practices is vital for teacher (and adult) learning. Teacher learning opportunities within the oTPD- STEM program in this study were planned using the reflective practices framework, allowing teachers to engage in deliberate episodes of reflection-on-action (Schön, 1983) with the intent of increasing communication to validate insights from the critical reflection followed by action informed by reflective practice (Mezirow, 1991).

Community of practice. Community of practice is grounded in Lave and Wagner's (1991) theory of situated learning, which proposes that knowledge is created through reflection with others who have similar experiences. Wenger (2011) describes communities of practice as "groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (p.1). This implies that communities of practice for practitioners should incorporate the view that developing one's knowledge for teaching should be an active and social endeavor.

Lave and Wagner (1991) suggested that legitimate peripheral participation in a community of practice is the key to optimal learning. Communities of practice connect learners with a community of acting practitioners where they can participate in legitimate activities, and gradually learn new knowledge and skills. Legitimacy of participation refers to "ways of belonging, and is therefore not only a crucial condition for learning, but a constitutive element of its content" (Lave & Wagner, 1991, p.35). Peripheral participation describes the "multiple, varied, more or less engaged and inclusive ways of being located in the fields of participation defined by a community…is about being located in the social world" (Lave & Wagner, 1991, p.35). Lave and Wenger (1991) also pointed out that peripherality was a positive term that suggested connectedness, relatedness, and relevance of activity and practice. They stated that "learners must be legitimate peripheral participants in ongoing practice in order for learning identities to be engaged and develop into full participation" (p.64).

Lave and Wenger (1991) also discussed community of practice, defining it as "a set of relations among persons, activity, and world, over time and in relation with other tangential and overlapping communities of practice" (p.98). They claimed a community of practice was "an intrinsic condition for the existence of knowledge" (p.98). Having established a definition of community, they turned to addressing the important issue of transparency and giving apprentices access to the activities, information, resources, and technologies of the community to enable them to engage in full participation. They suggested that motivation and identity construction would be the outcomes of legitimate peripheral participation.

In teacher professional development, communities of practice stimulate the improvement of teachers' professional practices (Lieberman, 1996). These communities provide collaborative learning opportunities among its members to define a shared vision for learning through continuous inquiry, reflection and evaluation of their own and peers' beliefs. This process of social learning is situated and deeply rooted in a cultural context that cultivates sharing and provides sustainable support for teachers. The concept of community of practice within oTPD-STEM in the current study was planned to allow participant teachers to collaboratively explore the novel idea of integration of STEM and support each other to adapt the idea to their own unique contexts.

The theoretical constructs of reflective practice and community of practice ground the exploration of the innovative education reform of integration of STEM in an online teacher professional development program in Pakistan. In this study, participant teachers were engaged in a community of practice for developing a shared understanding of STEM through deliberate acts of reflective practices.

Conceptual Framework for oTPD-STEM

The conceptual framework for oTPD-STEM was drawn from the theory of action (Kennedy 2016) that is embedded within the theory of (teacher) change (Wayne et al., 2008; Desimone 2009). Given the exploratory nature of this research study, it became even more significant to establish a conceptual framework to assert the natural progression of the participant teachers' understanding of STEM integration of the oTPD-STEM program. The literature review on professional development and research on the impact of a teacher professional development on teachers' classroom practice, in particular, led to the use of the theory of action (Kennedy, 2016) as a primary core idea of the conceptual framework to focus on this study's specific *problem of practice.* The specific aims were to (1) introduce Pakistani teachers to integration of STEM and devise a *pedagogy* that will help teachers enact integration of STEM in their classrooms and (2) translate this approach into the context of their own practice. The theoretical lenses of reflective practices and community of practice guided the theory of action by facilitating the problems of enactment of integration of STEM, to suggest a sustainable design for the oTPD-STEM program and to propose a model for integration of STEM in the Pakistani context.

For this study's specific *problem of practice*, introduction of integrated STEM, a strong theory of action was needed that could help participant teachers' exploration of the interdisciplinary venture of STEM integration. The proposed *pedagogy of practice*; model-enact-reflect, was rooted in coaching, reflective practice, and community of practice literature (Lave and Wagner, 1991; Knight, 2007; York-Barr, Sommers, Ghere, Montie, 2006). The theory of action for oTPD-STEM proposes the use of *problem of practice: introduction to STEM integration* to navigate through the innovative approach by employing *pedagogy of practice: model, enact, and reflect*. The *problem of practice* – introduction of STEM integration which involves interdisciplinary instruction, a collaborative, and team approach to *pedagogy of practice* involving a team of participant teachers – was employed. The participant teachers were first asked to "model" the curricular resources within their teams using the given written guidelines and video tutorials provided on the online learning platform, and then were asked to "enact" the curricular activities in the classroom that were initially rehearsed during the "model" part of this *pedagogy of practice*. However, this "model" part of pedagogy of practice is different than the usual acts of modeling in face-to-face PD, where the facilitator of the PD who is also an expert in the content, "models" in front of the participants allowing participants to clarify, question, and then move to the "enact" part where participants rehearse the curricular activities. Finally, the team of participants gathered to "reflect" on their enactment in the classroom which is a key to creating teacher change (York-Barr et al., 2006).

Theory of change focuses on the design features of TPD that promote change in teacher knowledge and/or practice (Desimone, 2009; Wayne et al., 2008) including its focused theory of action (Kennedy, 2016) about the specific problem of practice and a proposed pedagogy of practice that support teacher learning. This theory of change has allowed the researcher to connect the theory of action that was developed to facilitate participant teachers' understanding about integration of STEM within oTPD-STEM to the potential outcome of context-specific instruction design elements for oTPD-STEM and the participant teachers' evolution of understanding STEM integration. The conceptual framework for oTPD-STEM has theory of action at its core and is driven by reflective practices and implemented as community of practice tied to the broader theory of change (see Figure 2.6). This framework allowed the researcher to identify the key inputs, intermediate and final outcomes, and the variables that mediated and moderated the oTPD-STEM program within the context of a Pakistani school.

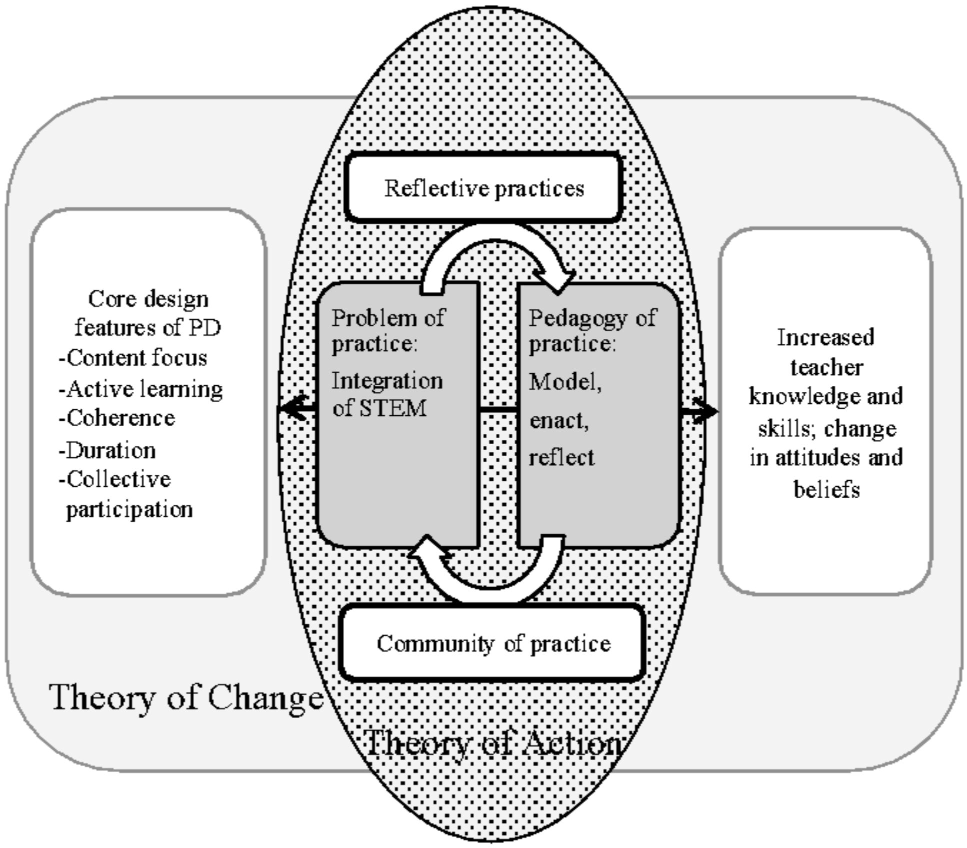


Figure 2.6. Conceptual framework for oTPD-STEM

The following chapter describes the design of the oTPD STEM program following a review of the literature and theoretical framework developed in this chapter. Chapter III also introduces design-based research as the methodology for the iterative design and research of the oTPD-STEM program. In Chapter III, details of the specific activities of oTPD STEM are presented in addition to the design-based changes that occurred as teachers' engaged in the learning and implementation of integrated STEM education.

Chapter III: Design-Based Decisions for oTPD-STEM

The core purpose for this chapter is to describe the design of STEM-focused online teacher professional development in Pakistan. This chapter first describes the overall instructional design elements that support STEM-focused online teacher professional development for Pakistani teachers. The following research question guided the development of a design-based oTPD-STEM program:

> What instructional design components make an effective online professional development program to support teachers' understanding of STEM integration? (Research question 1)

This chapter presents the methods and findings for addressing research question 1 in four main sections. It begins with first presenting the researcher's perspective for this study which is significant to understand the rationale for the Pakistani teachers' design-based oTPD-STEM program. The second section consists of a detailed overview of design-based research as the methodological framework which allowed the researcher to design, implement, improve, and suggest evidence-based heuristics for STEM specific, online professional development in Pakistan. The third section describes the evolution of the design-based oTPD-STEM program, which allows readers to experience the exploration, implementation, and finally, the evaluation phase of the oTPD-STEM program in this study. The final section discusses the key findings and describes the instructional design components of the oTPD-STEM program that supported participant teachers' understanding of STEM integration.

Researcher's Perspective

Researcher's Background

The researcher's perspective of design-based research is critical. The designer plays the role of change agent as well as evaluator which may be problematic in traditional research paradigms. The researcher's personal background and role during the development and implementation of the oTPD-STEM program is important given the exploratory nature of this study. The researcher was a doctoral candidate in Ph.D. STEM Education when she developed the oTPD-STEM program, and previously had seven years of experience as an elementary/middle school science teacher in Pakistan in the Canal View School System (CVSS) where this study took place. The researcher also had designed, planned, and facilitated various professional development activities and programs for teachers as a teacher educator at CVSS for about nine years.

Given the researcher's interest in learning about STEM-specific online teacher professional development, she became a part of the research team in an NSF-funded Noyce grant that explored an online Teacher Induction Network (TIN) and also worked as an instructional coach and curriculum writer in a NSF-funded Mathematics and Science Partnership project, and an Engineering to Transform the Education of Analysis, Measurement, and Science (EngrTEAMS) team. These practical immersive experiences shaped the researcher's ideas to transform the use of time and space for STEM learning through an online teacher professional development program and to recognize various models of STEM integration. Highlighting the researcher's background denotes how these personal interpretations and past experiences were incorporated into the study.

Researcher's role in the oTPD-STEM program

If a researcher is involved in the conceptualization, design, and implementation of a design-based program, then ensuring that the researcher makes credible and trustworthy assertions is challenging (Barb & Squire, 2004). Design-based researchers do not simply observe interactions but they cause the interactions on which these claims are made. The independence of the researcher, the integrity of the program, and the learning context are non-operative given the goal of design-based researchers to directly impact practice, while advancing theory that will be useful to others. Hence, the role of the design-based researcher is not to "sterilize" the naturalistic setting, but instead, the challenge is to develop flexibly adaptive theories that remain useful even when applied to new local contexts.

The researcher's roles during the development of the oTPD-STEM program were designer, facilitator, and researcher. Each role remained equally demanding and challenging. As the designer, the researcher went through an iterative process of reflection, enactment, and adaptation. She held an insider's perspective having previously lived in the same city and worked in the same school system where the study took place.

This insider perspective impacted the initial conceptualization of the oTPD-STEM program, but following interactions with the participant teachers, the researcher was forced to shift her perspective from an insider to an "outsider who was once an insider." Thus, this self-awareness led the researcher to reframe the research agenda, adapting it to the participant teachers' contextual requirements.

Design-Based Research

Overview and Background of Design Based Research

Design-based research (DBR) provides the most appropriate methodology for approaching the problem of making STEM-specific teacher professional development accessible to in-service teachers through an online environment. Design-based research is an emerging, formative research methodology approach that originates from the work of Brown (1992) and Collins (1992). DBR was first created for the following three reasons: (1) inadequate connections between research and the real learning context of research in laboratory experiments (Brown, 1992, Barab & Squire, 2004), (2) the need to create innovative solutions to problems in schools (Sandoval 2014; Sandoval & Bell, 2004), and (3) the often neglected significance of bridging research and practice (Design-Based Research Collective [DBRC], 2003).

Proponents of DBR offer multiple applied arguments to explain how DBR contributes to education research and practice. First, it offers strong connections between research and practice by situating research in the context of the school setting and focusing on innovative solutions to problems in schools, student learning, and teacher professional development (Brown, 1992). Another key feature of DBR is offering "usable" knowledge to both researchers and practitioners (Brown, 1992). Usable knowledge gained through the design of innovative learning environments both adds to the existing body of knowledge about teaching and learning and provides information about how such environments work in the setting for which they are designed (Cobb, Confrey, Lehrer, & Schauble, 2003; DBRC, 2003; Edelson, 2002).

The strength of DBR is in its flexibility in refining and expanding existing approaches to inquiry (McKenny & Reeves, 2012), explanatory power, ecologically situated contexts, grounding of internally consistent experiences, considering whether the intervention and theory connect and accurately reflect the truth about theory, and the outcomes in the design (Edelson, 2002). McKenney and Reeves (2012) described the key features of design-based research that distinguish it from conventional methodologies as follows: the operative goal to put theory into action, modifying an intervention to achieve ecological validity and most significantly, unlike conventional methodologies, DBR positions participants as collaborative partners by allowing sustained interaction that is beneficial to both researchers and participants.

Many calls have been made to specify the techniques for conceptualizing design-based research. Critics of DBR state two major concerns: the methodological rigor (Dede, 2004; Kelly, 2004), and the possibility of simultaneous design evaluation and theory building (Phillips & Dolle, 2006).

Rationale for DBR

The rationale of this study aligns with Van den Akker et al.'s (2006) three main motives for using DBR: (1) the desire to increase the relevance of research for educational policy and practice; (2) the goal of developing empirically-grounded theories through combined study of both the process of learning and the means supporting it, and (3) the aspiration to increase the robustness of design practice. This study fits within the domain of design-based research methodology due to characteristic features that this methodology offers to introduce integration of STEM using an online teacher professional development program in Pakistan. The characteristic features of DBR that align with this study are as follows.

Collaborative. DBR encourages intensive collaboration (Reeves, Herrington and Oliver, 2005; McKenney and Reeves, 2012) among all the participating members. It stresses the mutual benefits to both the researcher and participants who facilitated the researcher-practitioner partnership in the oTPD-STEM program. This social interaction for learning about the integration of STEM led to specific design features of the oTPD-STEM program to address the specific needs of Pakistani teachers. Ongoing collaborative learning interactions with other participants and the researcher also contributed to improved design solutions for the oTPD-STEM program throughout the study.

Addresses complex problems. Existing research offers minimal design principles to guide the integration of educational technology into teaching and learning. DBR allows researchers to have access to educational settings to understand complex problems and suggest robust solutions. This study considered the complex problem of introducing integrated STEM as an educational reform in an international context. The movement of a U.S.-based reform into an international setting created a complex scenario, and DBR facilitated the transformation of unforeseen complications into new opportunities for implementation of new design models (Brown, 1992) within the oTPD-STEM program.

Theory-driven. Edelson (2002) describes the theory-driven nature of DBR as a strong feature given that "the strength of theories developed through design research comes from their explanatory power and their grounding in specific experiences" (p. 113). Edelson (2002) further elaborates the characteristic feature of theory development within DBR as "the possibility of using the lessons learned in constructing design procedures, problem analyses, and design solutions to develop useful theories" (p. 112). This study required flexibility to adapt to the context of participant teachers, and DBR offered the possibility for the multiple iterations that evolved to facilitate Pakistani teachers' exploration of the novel concept of STEM integration. DBR allowed for collaboration with participating teachers, not only to test the initial theory- driven oTPD-STEM program but also to customize the oTPD-STEM program for Pakistani teachers.

The intent of oTPD-STEM is to generate what Cobb et al. (2002) calls humble theories to support STEM-specific professional development. They refer to them as humble theories because these theories are generated as a result of accountability to the activity of design.

Interventionist. DBR aims to design interventions or solutions for curriculum, software, professional development, school organizations, and school-community collaborations in real- world settings. Brown (1992) describes an effective intervention as one that "migrates from experimental classrooms to average classrooms operated by and for average students and teachers, supported by realistic technological and personal support" (p. 143). Similarly, Cobb et al. (2003) portray the interventionist characteristic of DBR as studies that "are typically test-beds for innovation" (p.10). In this study, the intent was to explore the novel concept of integration of STEM in Pakistan. The interventionist nature of DBR enabled the researcher to carry out this innovation in an online learning environment so participant teachers could visualize and enact integration of STEM in their local context.

Iterative. The iterative design of interventions incorporates cycles of analysis, design and development, evaluation, and revision. Multiple iterations of investigation, development, testing, and refinement help the educational design evolve over time. Wang and Hannafin (2005) elaborated on the iterative and synergistic process of DBR by defining DBR as "as a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real world settings, and leading to contextually- sensitive design principles and theories" (p.6). In order to create an online professional development program that could facilitate exploration of STEM in the local context of participants, the oTPD-STEM program in this study passed through continuous design, test, and reflection cycles.

Design of Intervention: oTPD-STEM

This study used a framework of a three-phase DBR design derived from McKenney and Reeves (2012). This generic DBR model comprises a single, integrated, research and design process. McKenney and Reeves' (2012) design process begins with the collaborative *analysis and exploration* of problems by researchers and practitioners; then it goes through *design and construction* that involves development of prototyping solutions that are grounded in existing theories, design principles, and technological innovations; and finally, the results in *evaluation and reflection* generate design principles and enhance contextually responsive practice.

The three-phase DBR design of the oTPD-STEM program in Pakistan includes six micro cycles, two meso cycle and one macro cycle. A meso-cycle contains micro cycles from more than one of the core phases, whereas in educational design research, macro cycle includes several meso-cycles over long periods of time. The first phase, the exploration phase, consisted of two micro cycles. The exploration phase began with a preliminary literature review that helped the researcher carry out initial conceptualization of oTPD-STEM 1.0 (see Chapter II). Second, participant recruitment was conducted by visiting the school to invite the administrator and the principals of the Pakistani school system to participate in this study. This opened the path for the researcher-practitioner partnership, as the researcher was able to meet with participants to elaborate on the purpose of this partnership and invite the teachers to be part of this collaboration. Sixteen teachers from three schools initially agreed to volunteer and signed the consent form (Appendix 3.1). Interviews with the participant teachers allowed the researcher to re-conceptualize the oTPD-STEM program with the local context in mind. The second phase of oTPD-STEM 1.0, the implementation phase, was initially designed as eight modules including a survey to determine the baseline requirements and to assess the learning needs of the participants after oTPD-STEM 1.0. During the implementation phase, a formal midway review and adjustment clarified the planned emphasis on adapting the oTPD-STEM program to participant teachers' needs. The two-way arrows between each part of the implementation phase in Figure 3.1 highlight the process of constant reflection and adjustments from both the researcher and participants. The third and the final phase, the evaluation phase, marked the completion of one macro cycle and the end of oTPD-STEM 1.0. Evaluation was intended to provide both theoretical and practical contributions as a result of reflection on the evaluation of the oTPD-STEM program.

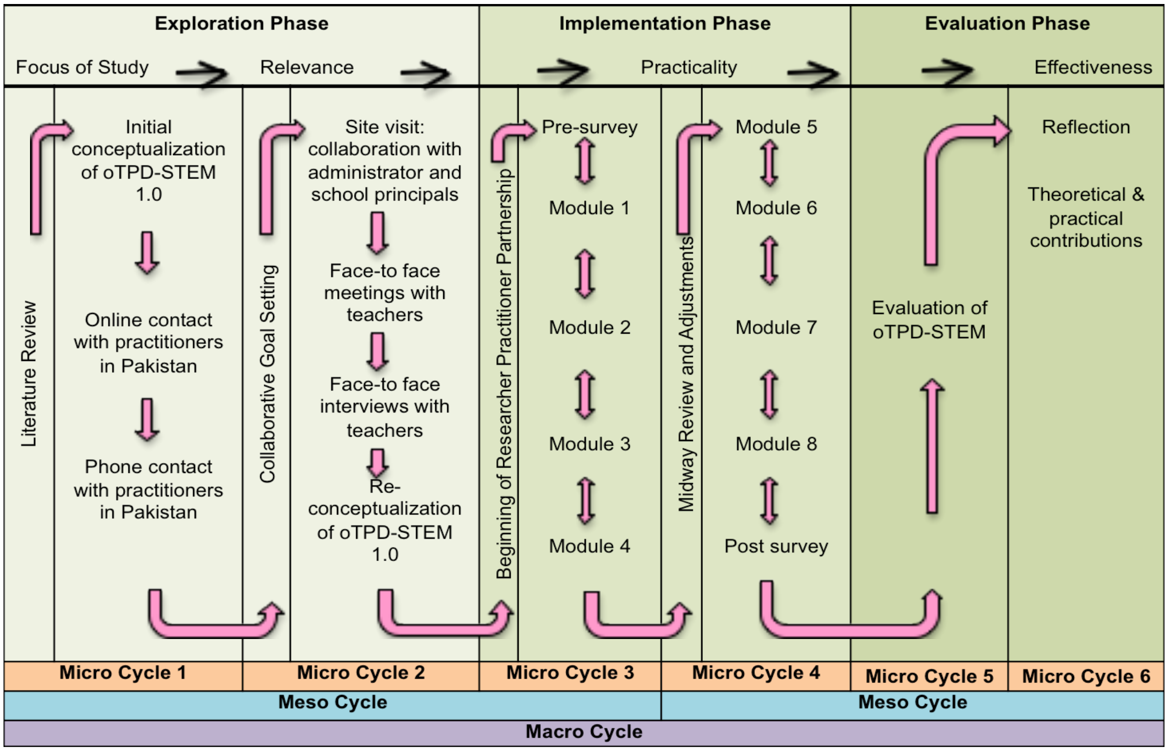


Figure 3.1. The three-phase design-based oTPD-STEM 1.0.

The original three-phase design-based oTPD-STEM 1.0 evolved throughout this study, resulting in the final design of oTPD-STEM 2.0. Below is a detailed account of the exploration, implementation, and evaluation phases to help the readers understand the design-based evolution of oTPD-STEM. The following research question guided the design of oTPD-STEM:

> What instructional design components make an effective online professional development program for supporting teachers' understanding of STEM integration? **(Research question 1)**

Exploration Phase

The exploration phase of oTPD-STEM 1.0 was theoretically grounded and based on a needs analysis of the specific context of this study. This detailed exploration paved the way for the initial design of oTPD-STEM 1.0.

Theoretical grounding. Lave and Wagner's (1991) community of practice and Schön's (1983) reflective practices served as the main theoretical underpinning of this study (see Chapter II for details). The exploration phase was grounded in the core idea of developing a community of practice that allowed the researcher to conceptualize the content of integration of STEM while the participant teachers were already participating in the oTPD-STEM program and also teaching students in their school concurrently. Throughout the oTPD-STEM program, the participants were supported as a community of practice so learning about STEM integration could transfer into their own classroom contexts by adapting to the information to the specific needs of the students, the teachers' personalized contexts, and the material challenges. Engaging in reflective practices also allowed the participant teachers to process their learning about integration of STEM.

Context of the study. For this study, the researcher chose a private school system in Lahore, the largest city in Punjab province and the second largest city in Pakistan. Private schools have been a key contributor to the education system of Pakistan since the denationalization of private schools in 1979. Private schools flourished during the 1990s and the extent of enrollment of students in private schools is one-fifth of all school-aged children in Pakistan (Nguyen and Raju, 2015). In 2010, the Institute of Social and Policy Sciences (I-SAPS) Islamabad presented a comprehensive report on Private Sector Education in Pakistan. According to I-SAP, from 1999-2008, the private education sector expanded by 69%, in contrast to an 8% increase in public schools. Out of the total educational institution enrollment in Pakistan, the private sector accounted for 32% in 2007-2008. The largest increase in private schools is found in Punjab where private educational institutions are 65% of all private institutions in Pakistan. In Punjab, the highest increase in private schools occurred in 1999-2000 with a 70% increase. Similarly, 44% of teachers worked in private institutions in the 2007-2008 school year.

Private schools in Pakistan are generally grouped into categories based on characteristics such as high- and low-fee schools, Urdu-medium and English-medium schools, and single sex and coeducation schools. Based on data shared in the Learning and Education Achievements in Punjab Schools (LEAPS) study, Andrabi, Das, Khawaja, Vishwanath and Zajonc (2007) indicated that students in private schools were outperforming public schools. In another study, Aslam (2006) also reported that private schools in Pakistan had better quality education compared to government schools. Andrabi et al. (2007) also described some typical characteristics of private school teachers as "young, single, moderately educated untrained local women" (p.4).

All of the participants of the oTPD-STEM program in this study were in-service teachers at the Canal View School System (CVSS), a pseudonym, that includes one purpose-built kindergarten, two elementary and two high schools, and two degree colleges (offering F.A./F.Sc./ICS/I.Com in disciplines of arts, science, computer science and commerce (equivalent to a high school diploma in the U.S.) and two-year B.A. B.Sc. and B.Ed. degrees in the disciplines of arts, science and education (equivalent to a community college two-year degree in the U.S.). CVSS began in the early 1990s when private schools were booming. CVSS serves the residents of the immediate and surrounding areas.

Curricular context of CVSS. CVSS has its own Department of Curriculum and Examination that ensures proper implementation of the curriculum and conducts centralized assessments. CVSS follows a combination of the National Curriculum of Pakistan and Cambridge International Curriculum. During the academic school year 2013-2014, a team of expert curriculum developers was hired to develop the curriculum for the school. At the time of the study, Canal View Elementary (CVE), where eight participants were teaching, was in the second year of implementing this curriculum. This new curriculum aimed to support both teacher and student learning. The curriculum for each subject had a detailed map of all the content, learning activities, and resources. The Department of Curriculum and Examination organizes and develops all academic policies, as well as the centralized assessments including mid-year and final exams. They also assist in improving discipline-specific teaching by providing comprehensive feedback through observations and regular follow up that identify the professional needs of teachers and recommendations for professional training.

Teacher professional development at CVSS. CVSS has its own Teacher-Training Department that provides on-going training and professional development services for their teachers. Teachers are engaged in professional development activities during alternate working Saturdays. In addition to these training days, weeklong professional development activities are arranged for teachers before and after the summer break.

Participants. The researcher invited all CVSS teachers who were teaching science, mathematics, and computer studies in grades 4-8. Participation in the research was voluntary. Initially, 16 participant teachers who worked at Canal View Elementary School (CVE), Canal View Elementary-Pioneer School (CVE-Pioneer), and Canal View Senior Girls School (CVSG) joined oTPD-STEM 1.0. Table 3.1 shows the demographic details of all the participants.

Demographic data was collected for all sixteen participants. Only three out of the sixteen teachers had one year or less of teaching experience. Five teachers out of the sixteen had teaching experience ranging from 4 years to 8 years. Five teachers had teaching experience ranging from 12-17 years and three teachers had 20 or more years of experience. All of the participant teachers from CVSG taught science and had a strong science background. Both of the participant teachers from CVE-Pioneer had undergraduate degrees with a science major and were teaching elementary science and mathematics. Only Sania from CVE had a teaching position corresponding to her qualifications; the other seven participant teachers had terminal degrees in different subject areas but were teaching science, mathematics, or computer studies.

Table 3.1

Participants of oTPD-STEM and demographic information.

Name	Qualifications	School	Teaching Subject	Grade	Years of Teaching Experience	Participated in oTPD-STEM
Fatima	M.Ed., B.A.	CVE	Math, Science	5	20	1.0 & 2.0
Shaheen	M.Ed., BSc.	CVE	Science, Math	5	12	1.0 & 2.0
Tania	M.A. Urdu, DIT	CVE	Computer Science	5	14	1.0 & 2.0
Bisma	M.A.English, B.Ed.	CVE	English, Science	5	23	1.0 & 2.0
Hina	MBA	CVE	Math	5	5 months	1.0 & 2.0
Sania	MCS	CVE	Computer Science	4, 5	12	1.0 & 2.0
Fareena	M.A. English	CVE	Math, Science	4	17	1.0 & 2.0
Bina	M.A.Pol. Sc., B.Ed.,B.Sc.	CVE	Science, Math	4	14	1.0 & 2.0
Saman	M.Sc. Psychology	CVE	Science, English	4	5	1.0
Razia	B.Sc. B.Ed.	CVE-Pioneer	Science, Math	4	7	1.0
Rabia	BS. (Hons)	CVE-Pioneer	Science, Math	3, 4	1	1.0
Rania	M.Phil. Biochemistry B.Ed.	CVSG	Science, Chemistry	8,9, 10	4	1.0
Atiya	M.Sc. Space Science, B.Ed.	CVSG	Science	7, 8	8	1.0
Humna	MSc. Applied Chemistry	CVSG	Science	6, 7	7	1.0
Maliha	B.Sc. Botany	CVSG	Science	6, 7	3 months	1.0
Muzna	M.Sc. Zoology	CVSG	Science, Biology	8, 9,10	20	1.0

Due to a variety of reasons (e.g., family commitments, resignation from job, no longer teaching science, math, or computer studies), eight participants exited the oTPD STEM program before commencement of oTPD STEM 2.0. Saman, a science teacher at CVE had to resign from the job due to personal reasons. Razia, from CVE-Pioneer, left due to family commitments. Rabia, also from CVE-Pioneer, left as there was no one else from CVE-Pioneer who continued with the oTPD-STEM program. Rania was one of the most active participants during oTPD-STEM 1.0, and was the only person who was comfortable using web 2.0 tools. She taught science in grade 8 in CVSG when oTPD-STEM 1.0 started but by the time oTPD-STEM 2.0 began, Rania's teaching responsibilities changed to teaching chemistry in grades 9 and 10, so Rania was unable to continue oTPD-STEM 2.0. Atiya had to go on leave for Hajj, just when oTPD-STEM 2.0 began. Maliha was a first-year teacher. She left because she was unable to balance school, oTPD-STEM, and home responsibilities. Muzna also found it difficult to manage work life balance and hence decided to leave the oTPD-STEM program. Humna, the only one left in CVSG, also decided to leave as there was no one left in oTPD STEM 2.0 with whom she could collaborate. The remaining eight participants, all from CVE, continued to participate in oTPD-STEM 2.0 throughout the entire study.

Sources of data. McKenney and Reeves (2012) discussed the importance of alignment between the research agenda and the data collection plan. Data collection methods selected for this study was entirely based on the research questions. Table 3.2

summarizes the data sources for research question 1; details for research questions 2 and 3 are discussed in Chapter IV. Multiple data collection methods were employed to yield a robust data set. The primary sources of data included interviews (a total of 930 minutes), reflective learning team conversations (a total of 600 minutes), a Google video call (120 minutes), Google forms: pre-post surveys and WhatsApp™ data. A detailed description of these data sources are described later as "Activities" under Redesign of oTPD-STEM 1.0 to oTPD-STEM 2.0.

Table 3.2

Questions and methods matrix (McKenney and Reeves, 2012)

Methods ➔ Question🡻	Interviews	Google Forms: Pre-Post Surveys	Google Video Call	Reflective Learning Conversations	WhatsApp Data
1. What instructional design components make an effective online professional development for supporting teachers' for STEM integration?	✓	✓	✓	✓	✓

Research timeline. The study took place from November 2014 to November 2016 (see Figure 3.2). The oTPD STEM program started with the *Exploration Phase* in November 2014. A face-to- face interview and online pre-survey was conducted with all sixteen participant teachers prior to the start of oTPD-STEM 1.0. The *Implementation Phase* commenced with the start of oTPD-STEM 1.0, occurring between April and June 2015. A Google™ video call was organized after oTPD-STEM 1.0 paused at the end of June 2015.

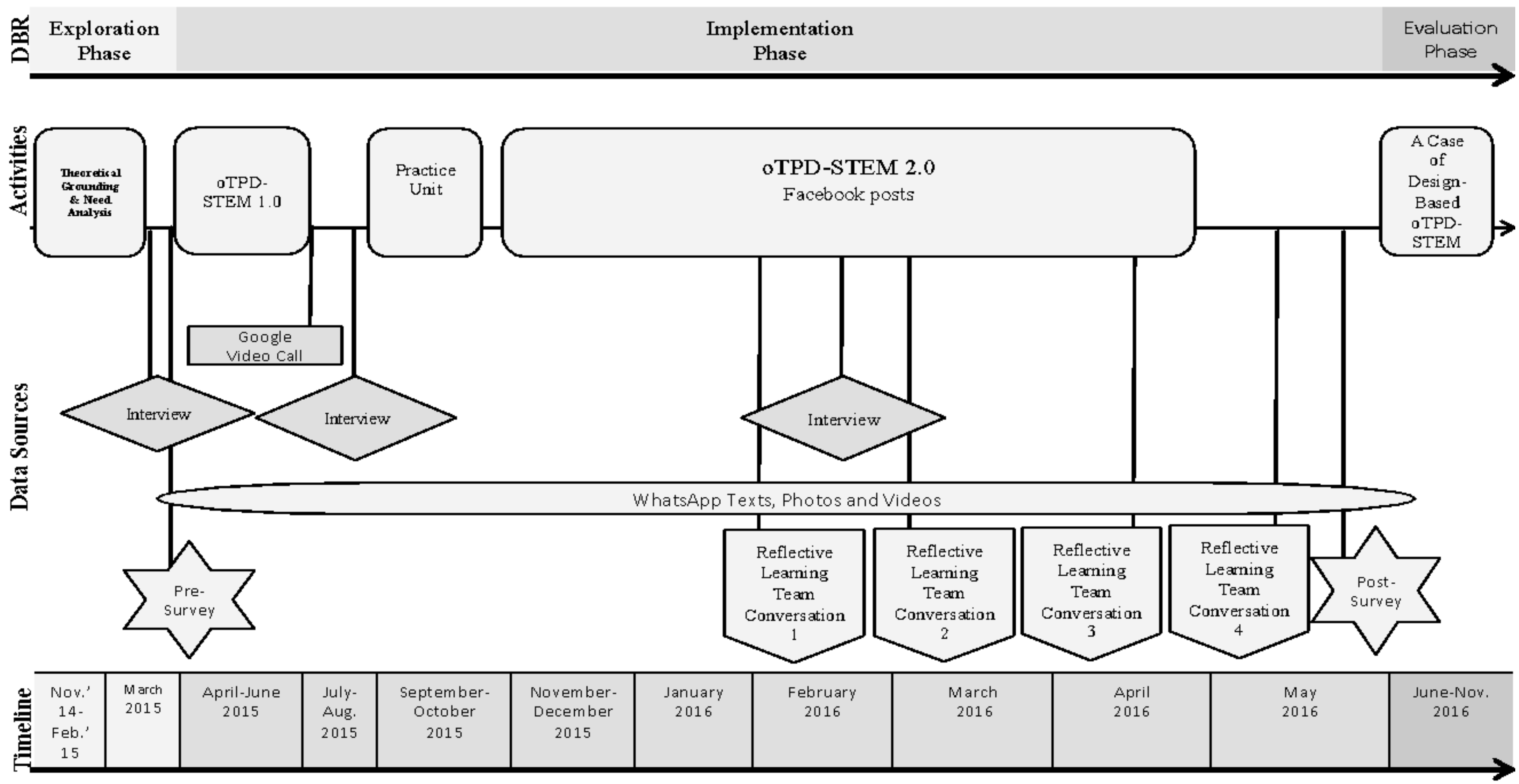


Figure 3.2. Timeline of design-based oTPD-STEM

Later, one-on-one Skype™ interviews were completed with fifteen participant teachers from July to August 2015. A practice unit was posted on the Facebook™ group in September 2015. oTPD-STEM 2.0 started in mid-November 2015 and ended in April 2016. During oTPD-STEM 2.0, another Skype™ interview was conducted in February 2016. Four reflective learning team conversations took place once in each month beginning in February 2016. Finally, a post survey was administered online at the end of May 2016. The *Evaluation Phase* lasted from June to November 2016, where extensive analysis, reflection, and evaluation occurred resulting in this dissertation study. WhatsApp™ data was generated throughout oTPD STEM 1.0 and 2.0 from April 2015 to May 2016. Details on each of the research phases are provided in the following sections.

Exploration phase data collection. The initial interaction with all the participant teachers was face-to-face. After the first interview, all of the interactions with the participant teachers were online. These initial face-to-face interviews held a significant place in beginning the researcher-practitioner partnership.

Face-to-face interviews. After the sixteen participants understood the nature of the oTPD-STEM program and signed the consent forms, each participant was interviewed individually. These audiotaped semi-structured interviews served as the baseline for conceptualizing the participant teachers' current understanding of STEM integration and the subsequent design of the oTPD-STEM program. In this interview, the researcher asked the participant teachers to describe each discipline (science, technology, engineering and mathematics), to elaborate on their views of "integration," to describe their understanding of integration of science, technology, engineering and mathematics, to share their experiences of integration of science, mathematics or any other discipline, and to share the strengths and challenges of integrating different disciplines (Appendix 3.2)

Pre-survey. The purpose of the pre-survey was to gather demographic data including prior TPD experiences, current teaching load and activities at school, expectations of the oTPD-STEM program, preferred medium of communication, and suitable times/days for synchronous meetings (Appendix 3.3). All participants responded affirmatively when asked about their comfort with online learning environments. All participants except Humna, Saman, and Fareena preferred to interact in Urdu or Roman English (Urdu written in English script). As the oTPD 1.0 began, this preference became visible through participants' interactions.

Design of oTPD-STEM 1.0. The oTPD-STEM program was designed with the intent to introduce the international education reform standard of STEM integration in the specific and local context of Lahore, Pakistan. oTPD-STEM 1.0 was designed as an eight-week module-based TPD. Each module contained six activities with the purpose of engaging participant teachers in current research, classroom practices in STEM education, and reflective discussions about integration of STEM including how this concept could be adapted to their unique contexts. Module 1, "Getting Started," was designed for the participant teachers to gain familiarity with the online environment and the online tools of the oTPD-STEM program. Table 3.3 provides an overview of the oTPD-STEM 1.0 modules along with the associated learning goals.

Learning goals of oTPD-STEM 1.0. **The** oTPD-STEM program had five main learning goals: (1) identify, describe, and apply the elements of integrated STEM, (2) appraise and describe integration of STEM as an approach, (3) recognize the benefits of a researcher-practitioner partnership, (4) design, pilot, and redesign a mini integrated STEM unit, and (5) examine integration of STEM in their Pakistani context.

Table 3.3

An overview of oTPD-STEM 1.0

Module	Title	Learning Goals
1	Moving Towards STEM	-Develop a common understanding of best teaching practices -Describe integration of STEM as an approach
2	Identifying Elements for Integration of STEM	-Identify, describe, and recognize the elements of integrated STEM
3	Analyzing Engineering Design Process	- Analyze the engineering design process to use it in integration of STEM
4	Exploring Local Context	-Recognize that knowledge is context specific -Explore integration of STEM by creating a local context that is motivating for Pakistani students
5	Examine Scientific Inquiry	- Examine inquiry-based practices in integrated STEM
6	Putting it All Together: Design a Mini STEM Unit	-Synthesize a mini STEM unit using the elements of integration of STEM
7	Pilot a Mini STEM Unit	- Reflect upon their own unit and offer critique as a critical friend to the partner team
8	Redesign a Mini STEM Unit	- Reflect on the whole process of designing a mini STEM unit -Propose a model for STEM integration in the Pakistani context

Activities. Each module contained activities that required readings, videos, discussions of the videos in a forum, listening to VoiceThread™ and posting audio comments, and one classroom activity. This activity was designed for translation of research into practice purposes so participant teachers could engage students in their classrooms and to gather students' ideas/ responses on integration of STEM (see Table 3.4).

Activities involving reading, watching videos, and listening to VoiceThreads required the participant teachers to think about the research on integration of STEM and then process this information to formulate their ideas to discuss with peers. Classroom activities were designed to provide participant teachers with opportunities to practice research-based practices from the readings and videos. Finally, participant teachers were asked to reflect on their own teaching practices, acknowledge what they practiced and what was needed, and share their concerns/fears about integration of STEM.

Table 3.4

Learning activities of oTPD-STEM 1.0

Module	Learning Objectives	Instructional Tools/ Activities	Description This activity asked participants to…
1	Identify best teaching practices	VideoAnt™	● Watch any three of four TIMSS study videos and annotate teaching practices noticed.
		Forum	● Discuss how the local context informs the teaching practices in the TIMSS videos and also share similarities and differences among the videos.
	Visualize integration of STEM	Reading	● Read the 2010 Bybee article.
		VoiceThread	● Listen to the VoiceThread that briefly narrates principles from research on integration of STEM;

			share lesson learned from research and teaching practices needed for STEM integration as an audio comment in VoiceThread
		Classroom activity	● Ask students to brainstorm and list problems that they find around them in their neighborhood, city, or province
		Flipgrid	● Reflect on their own teaching practices-acknowledge what you practice and what is needed; also share concerns/fears about integration of STEM
2	Identify the key elements in an integrated STEM unit	Video	● Watch the video "STEM Education: Developing 21st century skills"
		Reading	● Read the 2014 Moore et al. article and STEM curriculum unit "Save the sea birds"
		Google docs	● Analyze a STEM curriculum unit "Save the sea birds"
	Share personal idea/perspective of integration of STEM	VoiceThread	● Listen to a VoiceThread that briefly narrates research on different perceptions of integration of STEM; share as a audio comment in the VoiceThread
		Classroom activity	● Show PowerPoint " What is engineering?" to students and ask students to describe engineering
		Make It Better	● Reflect on the week's module and share a personal perspective of STEM integration and also suggest what else could have facilitated their understanding about integration of STEM

Each module included a concluding activity as a reflection on the module itself. Participants were asked to think about the activities they had done during the module and then were asked to describe what worked, what did not work, and ideas they had for improvement and adaptations. In Module 1, participant teachers were asked to post their video reflections on Flipgrid while in Module 2, these participants were asked to write their reflections in "Make it better." The complete learning activities of Modules 1-8 of oTPD-STEM 1.0 are in Appendix 3.4.

Design decisions. During the exploration phase, many factors impacted the design decisions for the oTPD-STEM program. The biggest challenge during this phase was developing interactions with and among participant teachers. Communication through email did not work well, and consequently WhatsApp became the on-the-go communication tool throughout this study. The design decision for the use of WhatsApp, in addition to instant messaging, was supported by the evidence of developing community among preservice teachers in a study conducted by Doering, Lewis, Veletsianos and Nicholas-Besel (2008). Results from various studies conducted in Pakistan, the specific context of this study, also encouraged the researcher to use WhatsApp in this educational context (Ahmed, 2016; Khan, 2016).

Based on the pre-survey data, all participant teachers identified themselves as intermediate to proficient level online users. Thus, the researcher chose Modular Object-Oriented Dynamic Learning Environment (Moodle 2.8) as the learning management system (LMS) for the oTPD-STEM program. Moodle was built for learning environments globally with flexible tools for both blended and online learning. Moodle also allowed the integration of Web 2.0 tools such as Flipgrid, VoiceThread, and discussion forums to provide online space for collaboration through discussions, and we also added VideoAnt for developing reflective practices (McFadden, Ellis, Anwar, & Roehrig, 2014; Ellis, McFadden, Anwar, & Roehrig, 2015) of participant teachers.

Moodle also allowed easy embedding of videos, especially the video tutorials for participant teachers using Screencast-o-Matic.

Implementation Phase

After thorough planning, the oTPD-STEM program entered the implementation phase. This phase involved implementation of oTPD-STEM 1.0 and later the redesign of oTPD-STEM 1.0 to oTPD-STEM 2.0 for the purpose of promoting increased participation.

Implementation of oTPD-STEM 1.0. Before starting Module 1, participant teachers were required to enter the Moodle site through a secure password-protected login ID. This first step was difficult for most participant teachers. A few of the participant teachers (Sadaf, Sania and Fareena) asked if they could directly reach the Moodle site for the oTPD-STEM program and skipped the login procedure. After some struggle, all of the participant teachers were able to log in to the Moodle site (Moodle, hereafter) and the oTPD-STEM program formally began.

Module 1, “Moving Towards STEM,” included learning goals of developing a common understanding of the best teaching practices for science and introducing participant teachers to integration of STEM as an educational approach. The various tasks were designed to engage the participant teachers in the introductory module. The participant teachers were first asked to watch any three of the four videos posted on Moodle from the TIMSS study and to annotate the teaching practices using VideoAnt

(Hosack, 2010). VideoAnt is a free, web-based video annotation tool for mobile and desktop devices that allows secure sharing and commenting on videos with groups of participants. Next, participant teachers were asked to discuss how the local context informed the teaching practices in the TIMSS videos and also to share the similarities and differences in each of the videos. Later, participant teachers were assigned to read the seminal work of Bybee (2010) on STEM education with a follow-up task of listening to a VoiceThread, a narrated media program that allows others to comment, which narrated research on integration of STEM. The participant teachers were asked to make an audio comment on VoiceThread about the lessons they had learned from the teaching practices in the TIMSS videos and the current research on STEM.

Another important part of each module was creating space for connecting theory to practice. For this purpose, participant teachers were assigned a "classroom activity." In *module 1*, participant teachers were asked to have students think about problems that exist around them that need immediate attention, to list them, and then to start thinking about the possible solutions.

The final activity for each module was each participant teacher's video or written reflection on the module. In *module 1*, the participant teachers were assigned to do a video reflection by considering their own teaching practices and sharing their concerns about STEM integration on Flipgrid. Flipgrid is an online tool that allows the user to respond with no more than a 90-section post to a grid topic with recorded videos to discuss, reflect, and share via webcam, tablet, or mobile device. It was used to share teachers' reflections as a 90-second, time-restricted dialogue on their learning at the end of a module. This task required the participant teachers to share their ideas in 90 seconds, and to listen and respond to their peers' responses and alternate viewpoints.

The participant teachers were challenged from the beginning of the module mostly with technology compatibility issues. The first activity used videos that were hosted on YouTube but YouTube was blocked in Pakistan at the time. Similarly, VideoAnt also relies on access to YouTube. The participant teachers were also unable to access Flipgrid, as it was not compatible with the Android devices used by most of the teachers. In order to troubleshoot, the module was extended for another week. The participant teachers sent pictures of students' responses to the "classroom activity" through WhatsApp (a closed-group social media application) as they found uploading pictures on Moodle too difficult. After spending two weeks including troubleshooting problems with *module 1*, *module 2* was posted with a gentle reminder to respond to all of the activities in *module 1*.

Module 2, "Identifying Elements for Integration of STEM," was designed to help teachers identify, describe, and recognize elements of integrated STEM. The participant teachers were asked to watch the video "STEM Education: Developing 21st century problem solvers" (TEDx Talks, 2014) posted on Moodle, followed by reading an excerpt on a STEM integration framework from a research paper on Implementation and

Integration of Engineering in K-12 STEM Education by Moore et al. (2014) and the STEM curriculum unit "Save the Sea Birds." The participant teachers were then asked to identify elements of STEM integration and collaboratively analyze the STEM curriculum unit by focusing on the elements of STEM integration in small teams using Google Docs. Third, participant teachers were asked to listen to a VoiceThread that narrated research on different perceptions of integration of STEM and to share an audio comment in VoiceThread about their personal perceptions of STEM and how this related to any of the researched perceptions of STEM. In the "classroom activity," the participant teachers were asked to show a PowerPoint presentation "What is engineering?" to students and ask students about their ideas of engineering. Finally, the participants were asked to reflect on *module 2* and share their personal perspectives of STEM integration and suggest what else could have facilitated their understanding about integration of STEM in "Make it Better" through a written reflection.

The participant teachers were again uncomfortable reading and posting responses on Moodle. With the exception of Rubab, Rizwana, Madiha, and Muneeza, the participant teachers did log in and explore *module 2*. They asked clarification questions through WhatsApp, for example, "What details do we need to consider as we look into the STEM curriculum unit?" "Can we do the analysis of STEM unit in Word instead of Google Docs?" Again, the participant teachers sent pictures of their students in response to the "classroom activity" through WhatsApp but the pictures only showed students' current schoolwork and not the task assigned in *module 2*.

Considering the participant teachers' incomplete responses in the first two modules, a Google video call was scheduled in week four using the participant teachers' availability data from each participants' Google form "All about you." Fatima, Shaheen, Tania, Bisma, and Bina, were able to join the call and they discussed what worked and what needed to be modified. These five participants said their pace was slow due to the fact that the academic session was approaching for the summer holidays and they were very busy with students at school. They found Flipgrid the most challenging technology, but they wanted to give it one more try and then report to me. The teachers did not complete the remainder of the activities in both the modules because of time constraints and new technology tools that required more exploration. The Google video call ended with a unified agreement that participants would complete *modules 1* and *2* and then would be consistent in completing the upcoming modules.

Despite their agreement, however, the participant teachers remained unable to complete the oTPD STEM assignments and instead asked to take a break from oTPD-STEM 1.0 for four main reasons: (1) They wanted to start the oTPD-STEM program after school reopened in September; (2) They felt that Moodle was overwhelming due to its academic outlook and they were overwhelmed by the use of reflective and collaborative tools likeVideoANT, Flipgrid, Voice Thread, and Discussion Forums; (3) They wanted an accessible, familiar, and preferably mobile version of the oTPD-STEM tools; and (4) They shared their frustrations with time constraints and believed that the activities and tasks should require limited to no written response.

Design decisions. The participant teachers faced various challenges with oTPD-STEM 1.0. The first challenge was logging into the secure Moodle 2.8 learning management system (LMS). Almost all participants communicated via WhatsApp that they needed assistance logging into Moodle. The participant teachers suggested a Facebook-like platform as a possible learning management system for the oTPD-STEM program. Interestingly, several other research studies have also suggested that a Facebook group could be used as a potential LMS for teaching and learning (Deng, Tavares, 2013; Grosseck, Bran & Tiru, 2011; Sanchez, Cortijo & Javed , 2014; Wang, Woo, Quek, Yang & Liu, 2012).

The second barrier was the participant teachers' inability to view videos either as educational YouTube videos or videos embedded into VideoAnt. It was quickly discovered that YouTube was banned in Pakistan at the time. To overcome this issue, Dailymotion was used instead. For the purposes of this study, both YouTube and Dailymotion were equally supportive.

The third challenge for the participant teachers was that Flipgrid did not work on their Android devices. This issue highlighted the participant teachers' preference for a mobile-friendly oTPD-STEM program. One of the most active participant teachers, Shaheen, commented on WhatsApp:

> I am a notification away of what you post on our Facebook group ☺ Even if I am cooking, as soon I hear Facebook notification… I quickly check what's new there! This is why you can hear back from me…and I find it very handy to share pictures, comments, links …all these using my phone
> (Shaheen, WhatsApp comment November, 2015).

Another challenging feature of oTPD-STEM 1.0 was the weekly, modular format. The participant teachers continually shared their day-long commitments at school and mentioned that the time constraints prevented them from more active participation in the oTPD-STEM program. Fareena's, Bina's, Fatima's, and Bisma's responses highlighted their continuous struggles coping up with the weekly modular activities.

> It is hard for me to complete all the activities in one week's time…
> (Fareena, WhatsApp Comment May, 2015)

> We have so many things going at school and at the end of the day I can only push myself to read through all the posted activities! (Bina, WhatsApp Comment June, 2015)

> I watched the TIMSS videos but our module ended and I couldn't post my response (Fatima, WhatsApp Comment June, 2015)

> I am unable to complete *module 1*, Can you accept my posts by the end of next week? (Bisma, WhatsApp Comment June, 2015)

The researcher gathered the teachers' comments after oTPD-STEM 1.0 through individual Skype interviews during July and August 2015. At this time, participant teachers Rizwana, Rubab, Rani, Atiqa, Humera, Madiha, and Muneeza talked about their unique situations and decided to discontinue the oTPD-STEM program. The remaining eight participant teachers shared the challenges they faced, emphasizing their full-time teaching commitments at school, the intensive nature of oTPD-STEM 1.0, the online learning environment not being mobile-friendly and too many challenging technological tools. Some of the excerpts from the Skype conversations that took place during July and August 2015 are as follows:

> Well…our team wanted to complete *module 1and 2* but modules required lot more time then we initially thought. I wonder if this [oTPD-STEM] could work on mobile phones then we could have done better (Shaheen, Skype conversation, July 2015)

> There were so many tasks in each module …by the time I was able to understand what all we need to do, time for submission would end. Maybe if we can make it simpler…I mean just use a few tasks…few tools? (Hina, Skype conversation, August 2015)

> The videos…TIMSS videos were very interesting but I could not make VideoAnt work for me. I think we can make use of Facebook like simple thing where you can post video and all members can easily share their comments…just a thought …what do you say?
> (Fareena, Skype conversation, July 2015)

Finally after reflecting on the participant teachers' needs and suggestions, oTPD-STEM 2.0 was designed on Facebook since it is completely mobile-friendly and compatible with technology in Pakistan. Moreover, the closed group feature of Facebook allows document, file, folder sharing along with sharing pictures, videos, and links to various resources. oTPD-STEM 1.0 transformed into oTPD-STEM 2.0 based on the needs and ease of use for the participant teachers.

Redesign of oTPD-STEM 1.0 to oTPD-STEM 2.0. As a result of the participant teachers' responses to the initial oTPD-STEM program, constant reflection and evaluation of oTPD-STEM 1.0 led to its redesign. Thus, oTPD-STEM 2.0 originated as a customized teacher professional development program to respond to the needs of the participant teachers in this study using Facebook as the online learning platform (see Figure 3.3)

Figure 3.3. Screenshots of the Facebook oTPD-STEM group.

Learning goals of oTPD-STEM 2.0. The learning goals of oTPD-STEM 2.0 remained similar to oTPD-STEM 1.0 except for one additional goal (i.e., the sixth learning goal). oTPD-STEM 2.0 was designed to focus on six main learning goals: (1) identify, describe, and apply the elements of integrated STEM; (2) appraise and describe integration of STEM as an approach; (3) recognize the benefits of a researcher-practitioner partnership; (4) design, pilot, and redesign a mini integrated STEM unit; (5)

examine integration of STEM in the Pakistani context; and (6) engage in reflective learning conversations to process understanding of integration in the context of Pakistan. The sixth learning goal was added in response to the participant teachers' suggestion of lessening written responses to activities. Reflective learning conversations were added to provide participant teachers with deliberate opportunities to reflect on their participation in the oTPD-STEM program and on their enactment of a STEM exemplar unit in their classrooms. The major transformation took place in the online environment and design of the learning activities by connecting research-based curriculum with classroom practice.

Activities. The main activities in oTPD-STEM 2.0 included (1) STEM perception responses, (2) a STEM exemplar unit "Cool It" with resources, (3) four reflective learning team conversations that required participant teachers to share their experiences, ideas, and challenges, and (4) the development of a mini STEM unit. The STEM perception response asked for a brief written or verbal response at three different points: first in November 2015, second in March 2016, and third in May 2016 during oTPD-STEM 2.0. The researcher adapted the STEM exemplar unit "Cool It" from an original STEM unit "Save the Sea Birds" (Schnittka, 2009) to fit into the Pakistani context. The STEM exemplar unit included resources such as videos clips and tutorials to facilitate participant teachers' enactment of the unit in their classrooms. The STEM exemplar unit was adapted to the local context and contained minimal details so that the participant teachers could visualize integration of STEM by looking at the example and not be put off by the detailed explanation of each segment of the unit.

The reflective learning team conversations were planned to engage participant teachers in reflective conversations on (1) the integration of STEM, (2) the engineering design process, (3) scientific inquiry, and (4) perspectives of integration of STEM with special reference to existing research in the field. The reflective learning team conversations required the participant teachers to share their experiences, ideas, and challenges in exploring the integration of STEM and allowed them to connect research with practice. Finally, the development of a mini-STEM unit was the concluding activity which required the participant teachers to use the elements of integration of STEM (Moore, et al, 2014) to design a mini-STEM unit embedded in their local context. Table 3.5 contains a summary of the activities included in oTPD STEM 2.0.

In order to ensure that the design of oTPD-STEM 2.0 was aligned with the learning outcomes and the participant teachers' needs and ease of use, the participant teachers were invited to join the Facebook group, interact with group members, and share the science content they wanted to use for understanding integration of STEM. The participant teachers suggested two science content areas: (1) food and nutrition, and (2) heat. The researcher used the science content that was aligned with the participant teachers' curriculum and adapted it by using the STEM integration framework (Moore et al., 2014).

Table 3.5

Learning activities of oTPD-STEM 2.0

Post	Learning Objectives	Instructional Activities	Online Learning Environ-ment	Description This activity asked participants to…
1	Reflect on an integrated unit	Practice curriculum unit	Facebook group/ WhatsApp group	● Explore practice unit "Food, Nutrition and Health" in small teams. ● Model after watching video tutorial; claim, evidence & explanation using data on obesity in children in Pakistan ● Enact practice unit "Food, Nutrition and Health" in the classroom ● Reflect on the enacted practice unit "Food, Nutrition and Health"
2	Reflect on initial under-standing of STEM	STEM perception response-1	Facebook group/ WhatsApp group	● Depict a personal model of STEM integration using a picture, a few words, or diagram ● Describe a personal model in words ● Identify what experiences inform the personal model
3	Model, enact, and reflect on STEM exemplar curriculum unit	Claim, evidence & explanation Storyboarding Engineering design challenge	Facebook group/ WhatsApp group	● Explore the STEM exemplar unit "Cool It" in small teams. ● Model after watching video tutorial; claim, evidence & explanation using data on malaria in Pakistan ● Model after watching the video tutorial storyboarding to show how vaccines work ● Model after watching the video tutorial engineering design challenge to make a vaccine cooler to carry malaria vaccine safely. ● Enact the STEM exemplar unit "Cool It" in the classroom ● Reflect on the enacted STEM exemplar unit "Cool It"
4	Reflect on understand-ing of STEM after enacting an exemplar unit	STEM perception response-2	Facebook group/ WhatsApp group	● Depict a personal model of STEM integration using a picture, a few words, or diagram ● Describe the personal model in words ● Identify what experiences inform the personal model
5	Reflect on STEM the exemplar	Reflective learning team conversation 1	Facebook group for pre-	● Watch the video clip by National Academies of Sciences, Engineering and Medicine and think about what integration of STEM is

	unit and connect research and practice		conversa-tion prep resource Skype audio team call	● Watch the video tutorial about research on integration of STEM and think how the research can be connected with classroom teaching and student learning ● Share a personal teaching experience of the STEM exemplar unit ● Share how research can guide the practice of STEM
6	Reflect on the engineering design process and how it supports integration of STEM	Reflective learning team conversation 2	Facebook group for pre-conversa-tion prep resource Skype audio team call	● Watch the IDEO shopping cart video ● Watch the video tutorial about research on the engineering design process ● Share a personal experience of using the engineering design process in the classroom, its role in integration of STEM, role of context in framing a problem, role of working within constraints, and how research guides the practice of the engineering design process
7	Reflect on scientific inquiry	Reflective learning team conversation 3	Facebook group for pre-conversa-tion prep resource Skype audio team call	● Watch video clips on "What is scientific inquiry?" and "Example of scientific inquiry" ● Watch the video tutorial on research on scientific inquiry and its role in integration of STEM ● Share a personal experience of using scientific inquiry in the classroom, how this instructional approach can support the integration of STEM, how research in scientific inquiry guides practice of integration of STEM
8	Design a STEM unit	Mini STEM curriculum unit	Facebook group/ WhatsApp group	● Watch the video clips for STEM unit ideas ● Read the six research-based elements of STEM integration ● Design a mini STEM curriculum unit choosing content from the local curriculum and choosing a local context
9	Reflect on understand-ing of STEM after designing a mini STEM unit	STEM perception response-3	Facebook group/ WhatsApp group	● Depict a personal model of STEM integration using a picture, a few words or diagram ● Describe the personal model in words ● Identify what experiences inform the personal model
10	Reflect on a personal perspective of integration of STEM	Reflective learning team conversation 4	Facebook group, Skype audio team call	● Watch the video tutorial on research on integration of STEM ● Share a personal perspective on integration of STEM and how this model would be relevant to the local context in Pakistan

A unit on food and nutrition was adapted to a Pakistani context and posted on the Facebook group as *Food, Nutrition and Health* (adapted from the "Health and Nutrition Toolkit" by Simcox, 2012). This food unit was done as a practice unit. The intent of this unit was to give an idea of the integration of STEM in the simplest way without requiring many resources. In this unit, grade 4 and 5 students were expected to review the concepts of food groups and healthy eating habits and follow the engineering design process as they explored the problem of obesity. The Children's Hospital and the Institute of Child Health in Lahore invited students from different age groups to participate in their effort to raise awareness among children and youth to develop healthy eating habits along with healthy lifestyles. This unit asked students to use the data from the University of Washington's Institute for Health Metrics and Evaluation interactive data visualization tool that shows trends in obesity and overweight worldwide and by country for the years 1980-2013. The unit required students to use this interactive data to introduce them to evidence-based reasoning using a claim, evidence and explanation model, and allowed students to propose the best way to spread awareness in the community. Students were asked to plan, design, test, and redesign an "Obesity and Overweight Awareness Message" by suggesting the most cost-effective and time-efficient method of spreading this message. The whole unit including the summary, overview, and detailed breakup of the lessons was posted on the Facebook group (see Appendix 3.5).

The STEM exemplar unit “Cool It” was posted on the Facebook group in four segments. This unit was adapted from an original STEM unit “Save the Seabirds” (Schnittka, 2009). The researcher used the science content of heat as suggested by the participant teachers and adapted the unit for the Pakistani context. Post 3 of oTPD-STEM 2.0 describes the details of the STEM exemplar unit later in this chapter.

Implementation of oTPD-STEM 2.0 (Practice Round).

oTPD-STEM 2.0 began with a completely customized online learning environment by shifting several design and formatting issues: (1) changing from Moodle to a Facebook closed group; (2) using a modular technology rich PD format to be more participant centered – modeling based on exploration and enactment of an exemplar STEM unit; and (3) changing written task responses to more verbal responses and conversations on Skype. By this time, only eight participant teachers were able to continue with the study and complete oTPD-STEM 2.0 in its entirety.

Initial interaction on the oTPD-STEM Facebook group began when the researcher posted Post 1, a practice curriculum unit on *Food, Nutrition and Health.* All of the participant teachers viewed Post 1 on the Facebook group but did not comment for a week. Meanwhile, the researcher had the opportunity to implement this unit with a group of fourth and fifth graders in the U.S and posted her reflections on the Facebook group. This marked the beginning of formal interaction between and among the researcher and the participant teachers. The participant teachers had many clarifying questions for the researcher. Participant teacher Bisma’s conversation with the researcher and her team member Hina was quite detailed. They discussed questions concerning the enactment and logistics of the activities of the unit. Over the next two weeks, the participants shared their experience of enacting the *Food, Nutrition and Health* unit in their classrooms. This was done mainly through sharing their personal responses as WhatsApp comments, pictures, and videos of students’ responses (see Figure 3.4).

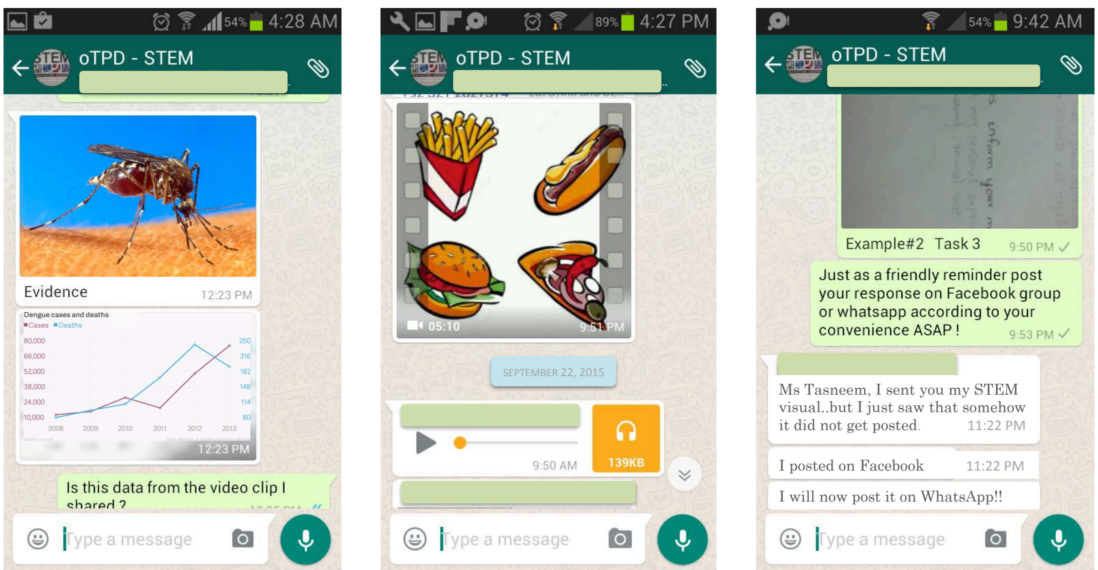


Figure 3.4. Screenshots of text, photo, video and voice chat in the WhatsApp oTPD-STEM group.

The participant teachers shared comments about the interest students took in working for The Children’s Hospital and the Institute of Child Health in Lahore to create awareness in the community. Similarly, the participant teachers shared photos of students’ work and of the students doing work. The participant teachers also shared their adaptations of this unit. They mostly shared photos of the students' teamwork activities, research work, and their final survey assignment. This data will be shared in the following chapter that explores research questions 2 and 3.

While the participant teachers were engaged in enactment of the practice unit *Food, Nutrition and Health*, the researcher continued reflecting on this new online learning environment for the oTPD-STEM program. The participant teachers viewed the unit overview and the detailed curriculum unit posted together as a huge big task and hence this took considerable time to begin working on the unit. Sania, Fareena, Fatima, and Hina mentioned during the WhatsApp chat that the practice unit seemed "huge," "big," and "may take more than four lessons." Their clarifying questions indicated that they needed a video tutorial describing how to carry out each lesson of the practice unit to address the learning goals for the students. WhatsApp was still the most prominent communication tool during this phase.

Design decisions. Reflections on the participant teachers' responses on the practice curriculum unit allowed for further review and adjustment in oTPD-STEM 2.0. After seeing the number of clarifying questions that were asked while exploring this practice unit, the researcher decided to continue the practice of including an accompanying video tutorial in each new Facebook post, which had been a regular feature in each module in oTPD-STEM 1.0. The researcher also decided to divide the next STEM exemplar unit into three smaller chunks instead of posting the complete unit on the Facebook group so the participant teachers could flesh out the details for each part of the curriculum unit.

Looking back at the most accessible, efficient, and popular communication and data sharing tool throughout this study, the researcher created WhatsApp groups for each of the three teams. This design decision provided each team with their own synchronous space to share ideas since they implicitly started interacting mainly on WhatsApp. The participant teachers could still use the main oTPD-STEM WhatsApp group if they needed to share with the larger group of eight participant teachers. The researcher noticed the potential use of WhatsApp groups (Main group and team groups) as a central learning environment and the Facebook group continued to be the main resource sharing platform for documents and videos. The participant teachers spontaneously switched from Facebook to WhatsApp because it was so easy to use. Shaheen stated, "WhatsApp is so easy; I can take a photo of students' work and send to you right away." The researcher communicated with participant teachers to share data on either the Facebook group or WhatsApp group. While the researcher made adjustments to oTPD-STEM 2.0, additional feedback from the participant teachers included a suggestion to postpone oTPD-STEM for two or three weeks so they could prepare students for the formal assessment at school along with co-curricular activities. In one of her WhatsApp comment threads in October, Bisma stated, "I am still doing the Food and Nutrition unit…our school is having annual sports day and next week we have our science exhibition." She continued to share her teaching and other responsibilities at school and then commented, "…once these co-curricular activities will end, reinforcement week will begin in November and finally the formal assessments…all in a row!" Bisma also seemed a little overwhelmed and talked about the plethora of activities lined up one after the other. She suggested, "Can we put oTPD on hold for 2-3 weeks and restart it with complete focus?" Shaheen, Hina, Sania, Bina, and Farah had similar affirming comments that backed up Bisma's last comment within a few minutes. Therefore, the researcher and the participant teachers mutually agreed to restart the oTPD-STEM program in mid-November 2015.

Implementation of oTPD-STEM 2.0 (Contd.). oTPD-STEM 2.0 restarted with Post 2 on the Facebook group. The first activity asked the participant teachers to draw on and explain their view of STEM integration and reflect on what informs their perceptions. They asked clarifying questions to understand Post 2, initiating multiple interactions among the participant teachers. Thus, oTPD STEM 2.0 became live again. One conversation snippet that took place among Fatima, Shaheen, Tania, and the researcher was about understanding the expectations from the STEM perception response where they asked various questions about the expectations for this task. All of the participants liked Post 2 but no one posted any response on the Facebook group. Some of the participant teachers emailed their responses while others shared them as a WhatsApp comment or photo. All of the participant teachers described their STEM perceptions.

Post 3 was shared on the Facebook group in November 2015 in four segments. First, the summary and overview of an STEM exemplar unit "Cool It" was posted on the Facebook group. Second, data showing the impact of malaria throughout the world and specifically in Pakistan was posted and the participant teachers were asked to explore the data using a claim, evidence, and explanation model (McNeil and Krajcik, 2008). Third, activities related to science/math content were posted on the Facebook group along with the video tutorial. These tasks involved implementing a scientific inquiry approach to the exploration of the concepts of heat and heat transfer. Lastly, the engineering design challenge of planning, designing, and testing a "model vaccine cooler" to keep the malaria vaccine at the required temperature was posted along with the video tutorial. Post 3 required the participant teachers to explore, model, and enact the exemplar STEM unit.

This exemplar STEM unit, "Cool It," was adapted for the Pakistani context from an original STEM unit "Save the Seabirds" (Schnittka, 2009). "Cool It" explored the concepts of heat and heat transfer in a local context of keeping malaria vaccines at the correct temperature. In the unit, the Directorate of Malaria Control (DMC) in Islamabad invites the schools to partner in solving the challenge of storing and transporting the precious malaria vaccines at the correct temperature for 10+ days, even when the power is unreliable. (Appendix 3.6)

Almost all of the participant teachers immediately liked this post. This time almost all of the teachers had something to share with the whole group. They explained in their reflective interviews that they liked the inquiry-based tasks of the STEM exemplar unit and their students also learned to back up their claims using data. The participant teachers also found the video tutorial helpful as it walked them through the steps of instruction in a simple way rather than “reading a detailed written curriculum document” as shared by Sania. The final task of the unit was an engineering design challenge that received considerable push back from the participant teachers. These teachers also continued to grapple with engineering design process.

Post 4 again asked the participant teachers to draw on and explain their understanding of STEM integration and also describe what factors influenced this understanding. Post 5 required the participant teachers to explore the concept of integration of STEM during “Reflective learning team conversation 1.” Post 6 asked the participant teachers to review the video tutorial to see the research perspectives on engineering as part of integration of STEM, watch video clips on how the engineering design process works and share ideas about the engineering design challenge in “reflective learning conversation 2.” Post 7, “reflective learning team conversation 3,” was about generating conversations on scientific inquiry. Post 8 required the participant teachers to design a mini-STEM integrated curriculum. Post 9 asked the participant teachers to draw on and explain their understanding of STEM integration and also describe what factors influenced this understanding as their final STEM visual. Post 10 was the culminating reflective activity that required the participant teachers to review of all of their work on integration of STEM, watch a video tutorial sharing various perspectives on integration of STEM that exist in research literature, and share their personal perspectives on integration of STEM in the final "reflective learning team conversation 4." The content of oTPD-STEM 2.0 is discussed in detail in the following chapter along with supporting data showing participant teachers' interactions within oTPD-STEM 2.0.

Evaluation Phase

This final phase provided an in-depth evaluation of the oTPD-STEM program as a whole. All of the data generated during oTPD-STEM 1.0 and oTPD-STEM 2.0 was referred to along with the researcher's reflective log that contained her personal thoughts on the design and implementation of the program. This phase required the consolidation of the experiences that took place during design, planning, and implementation of the oTPD-STEM program. In addition to the data generated throughout the program, the participant teachers responded to a post-survey. Below is an analysis of the instructional design elements used in the oTPD-STEM program to elicit possible affordances for the participant teachers followed by an overview of each team's participation in the oTPD-STEM program.

Instructional design elements used in the oTPD-STEM program. A post-survey of the oTPD-STEM program was conducted using online Google forms. The post-survey (Appendix 3.7) included two items that required the participant teachers to rate the learning tasks and learning environment of the oTPD-STEM program. The remaining four items were open-ended and asked the participant teachers to reflect on their experience during the oTPD-STEM program and to share their key learning, an example that described integration of STEM, challenges/support in the oTPD-STEM program and suggestions for improving the program experience in the future. All of the participant teachers except one responded to the post-survey.

In the post-survey, the participant teachers mostly responded in favor of the tasks that were included in the oTPD-STEM program. Five of the participant teachers considered the WhatsApp group chats (whole group) to be highly effective while three considered the WhatsApp individual chats (individual team) to be highly effective. Similarly, three of the participants rated the Facebook group posts as highly effective whereas another three participant teachers rated the tasks for the STEM exemplar unit as highly effective. Two of the participant teachers found Skype to be highly effective, four found Skype to be effective, and one found Skype to be just adequate (see Figure 3.5).

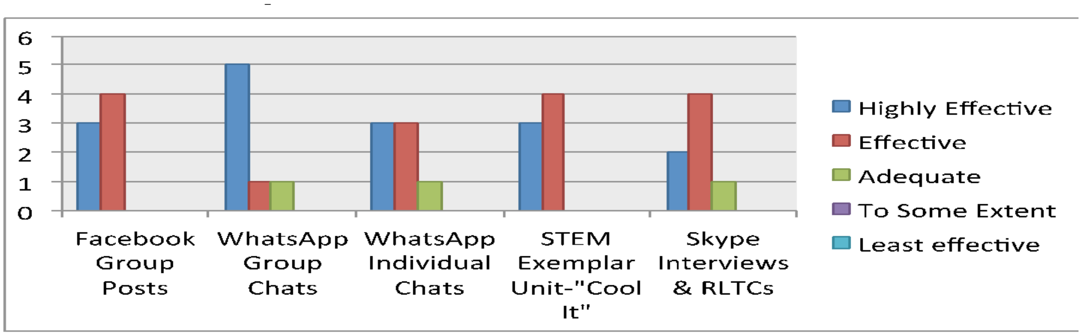


Figure 3.5. Participant teachers' responses on tasks that contributed to understanding of STEM

The participant teachers also provided some insightful suggestions for improving this online teacher professional development program. One of the participant teachers pointed out the usefulness of WhatsApp by stating; “WhatsApp worked the best for me in sending my students’work, videos, etc.” Another suggestion was to use WhatsApp voice chat instead of team Skype meetings due to the frequent dropped calls, but the rest were satisfied with the oTPD-STEM 2.0 tools. Participant teachers’ struggles with Moodle in oTPD-STEM 1.0 and the web 2.0 tools: Flipgrid, Voicethread, discussion forums, and VideoAnt are shared in detail under the implementation phase. Participant teachers’ formative evaluations during the implementation phase allowed for design decisions that informed the researcher when customizing oTPD 2.0 to better meet the participant teachers’ needs.

The post survey illustrates the affordances WhatsApp offered to participant teachers during the oTPD-STEM program. The usage data (see Figure 3.6) generated through the WhatsApp oTPD-STEM group also aligned with the findings from the post survey. All eight participant teachers used the WhatsApp oTPD-STEM group for communication, queries, sharing data, and collaboration. WhatsApp texts were the most widely used means of interaction among the participants and the researcher. Along with WhatsApp text, the participants shared data through WhatsApp photos and videos. Sometimes the participant teachers also used WhatsApp voice chat to either clarify or to respond to some activity or question verbally instead of sending a WhatsApp text.

The WhatsApp data generated through the oTPD-STEM group showed a gradual increase except for the instant increase in May 2015 when oTPD-STEM 1.0 began and the participant teachers texted their concerns about getting access to the secure Moodle site of the oTPD-STEM program followed by other technological constraints (see Figure 3.6). The participant teachers mainly relied on WhatsApp texts and sometimes responded using voice chat; however, they also continued to share their thoughts on the implementation of the practice unit and STEM exemplar unit data as photos and videos on WhatsApp. The WhatsApp group remained active even when oTPD-STEM 1.0 stopped and when oTPD-STEM 2.0 was being designed. The participant teachers continued to either suggest ways or inquiries about the plans for the oTPD-STEM program.

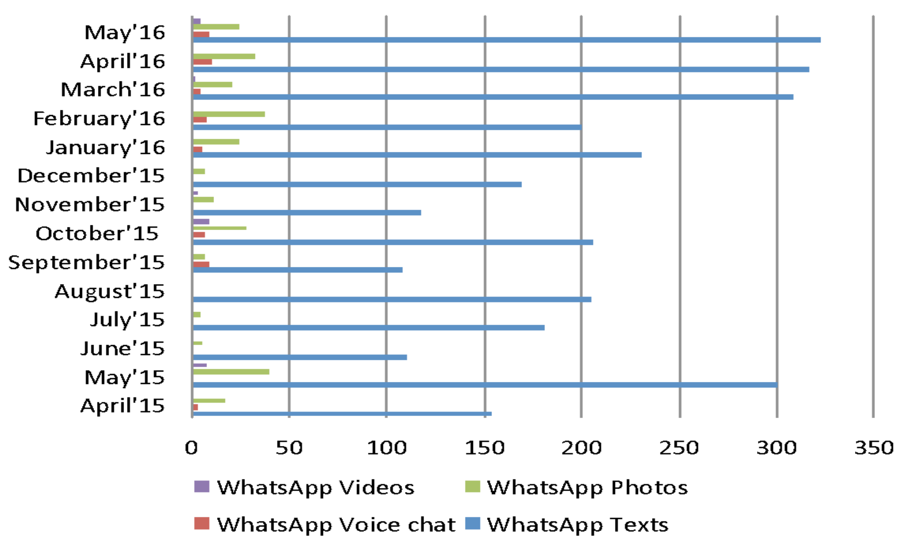


Figure 3.6. Bar graph showing data generated through the WhatsApp oTPD-STEM group from April 2015-May 2016.

The Facebook group emerged as a closed, private online environment used mainly for hosting learning activities of the oTPD-STEM program. The participants, especially Shaheen, Tania, Bisma, Fatima, and Sania, acknowledged the posted activity almost instantaneously by liking or commenting on the post. In addition to posting learning activities on the Facebook group, the researcher helped the participant teachers by posting video tutorials, video clips, photos, and files (Word documents and PDF files). The participant teachers sometimes commented on the posts but more frequently gave a thumbs up by liking the posts. All of the participant teachers viewed all of the posts on Facebook. The participant teachers asked to post the resources as Word or PDF files so they could use the hard copies while planning for the implementation of the STEM exemplar unit (see Figure 3.7).

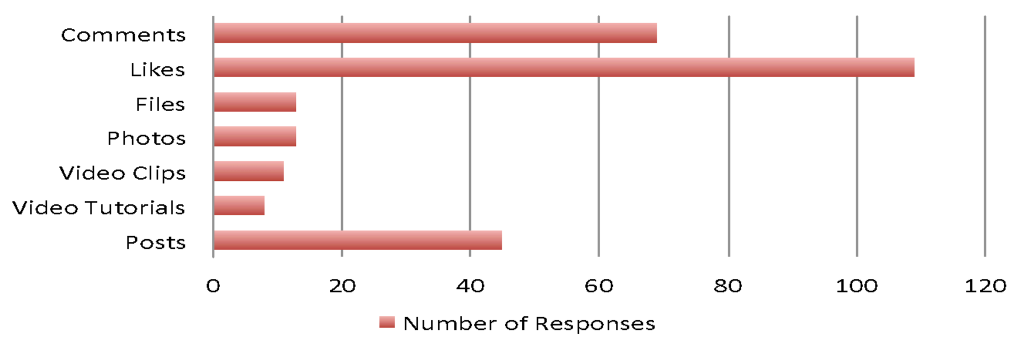


Figure 3.7. Bar graph showing data generated through the Facebook oTPD-STEM group from September 2015-May 2016.

Skype was the third most commonly used synchronous tool during the oTPD-STEM program. Three one-on-one interviews took place at three different times. One-on-

one interviews were smoothly conducted without any serious Internet connectivity issues. All of the participants were able to share their viewpoints except for Sania, Fareena, and Bina who were unavailable for the second interview (see Table 3.6).

Table 3.6

Interview data generated using Skype

Participant teachers Interviews	Fatima	Shaheen	Tania	Bisma	Hina	Sania	Fareena	Bina
Interview 1	30 min	25 min	35min	35 min	30 min	30 min	30 min	30 min
Interview 2	68 min	66 min	50min	60 min	55 min	-	-	-
Interview 3	56 min	60 min	60 min	60 min	60 min	35 min	25 min	30 min
Total data collected (in minutes)	154	151	145	155	145	65	55	60

During oTPD-STEM 2.0, Skype was again used for reflective learning team conversations. These conversations were carried out with each of the three teams, but sometimes the Skype group call connectivity was weak causing the call to drop or resulting in low audio. Team Fatima, Shaheen, and Tania completed all four reflective learning team conversations, whereas Team Bisma and Hina completed three reflective learning team conversations as a team on Skype but shared their reflections individually on the last conversation as a WhatsApp voice chat due to continuous Internet connectivity issues and unavailability of a common Skype meeting time before the end of oTPD-STEM 2.0. Scheduling reflective learning team conversations was the most challenging for Sania, Fareena, and Bina. The researcher had to modify these conversations to be an individual response reflective learning protocol (Appendix 3.8). Fareena and Bina responded to this individual response reflective learning protocol as WhatsApp voice chat while Sania did not respond to these individual responses at all (see Table 3.7).

Table 3.7

Reflective learning team conversations on Skype.

Teams Reflective Learning Team Conversations	Fatima, Shaheen, Tania	Bisma and Hina	Sania, Fareena and Bina
RLTC 1	60 min	60 min	0+ 15 + 15 min*
RLTC 2	60 min	60 min	0 +15 + 15 min*
RLTC 3	60 min	60 min	0 + 15 + 15 min*
RLTC 4	60 min	30 + 30 min *	0 + 15 +15 min*
Total data collected	240 min	240 min	120 min

*Participant teachers responded on WhatsApp voice chat using a reflective learning protocol.

The participant teachers worked in three small teams during the oTPD-STEM program except for Facebook Posts 2, 4, and 9 that required each individual participant to describe their own STEM integration perception. All of the participant teachers responded to the activities through Post 2, almost during the same timeframe. From Post 3 through the end of oTPD-STEM 2.0 each team's response time varied. Not only did the teams differ in the time of posting responses but also in the frequency of responses (see Table 3.8).

Table 3.8

Data generated by participant teachers' use of instructional design components in oTPD-STEM

Participant teachers'	Team Fatima, Shaheen, Tania			Team Bisma, Hina		Team Sania, Fareena, Bina		
Data sources	Fatima	Shaheen	Tania	Bisma	Hina	Sania	Fareena	Bina
Interviews	154 min	151 min	145min	155 min	145 min	65 min	55 min	60 min
Google Form: Pre-Survey	✓	✓	✓	✓	✓	✓	✓	✓
Google Form: Pre-Survey	✓	✓	✓	✓	-	✓	✓	✓
Reflective Learning Team Conversations	240 min			240 min		120 min		
WhatsApp Team data (Nov'15-May'16)	402 comments			265 comments		128 comments		

Team Fatima, Shaheen and Tania generated data on time and with appreciable interactions as a team and as individual participants. Team Bisma and Hina started very actively and with much enthusiasm but later encountered a unique situation. Bisma was transferred from CVE to CVSG School in September 2015 when the oTPD-STEM 2.0 practice unit was running. This team's collaboration was different than the other two teams in that both teachers were no longer working in the same building, so Bisma and Hina developed an alternative approach to model, enact, and reflect. Both participant teachers used their working Saturdays to collaborate on the oTPD-STEM program in one of the schools. After this face-to face collaboration, they communicated with each other on their team's WhatsApp group. Data submitted by Team Sania, Fareena, and Bina was mostly fragmented and represented individual responses rather than team collaboration. This team made minimal use of the online environments: Facebook and WhatsApp. The case of Team Fatima, Shaheen and Fatima is discussed in detail in Chapter IV to explore the development of conceptions of STEM throughout the oTPD STEM program.

Answer to Research Question 1: Design Principles for the oTPD-STEM Program

RQ1: What Instructional Design Components Make An Effective Online Professional Development for Supporting Teachers' Understanding Of STEM Integration?

The exploration of the design-based oTPD-STEM program and sharing the findings of this design-based research resulted in the creation of usable knowledge by the researcher-practitioner partnership as opposed to researchers developing findings in isolation for practitioners to consume (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; DBRC, 2003; Dede, et al, 2009; Edelson, 2002). As shared through the evolution of oTPD-STEM, the researcher together with the participant teachers continually interacted and reflected to adapt the design of the oTPD-STEM program to correspond to the needs of the participant teachers. The three main considerations for the design of oTPD STEM related to an accessible online environment, comfortable online interactions, and balancing the affordances of synchronous and asynchronous interactions in a community of practice to explore integration of STEM in Pakistan.

Accessible Online Environment

Access to the online environment is the entry point for any online teacher professional development program that is absolutely context specific. Online teacher professional development for participants from a certain geographical location must adapt to participants' views of an accessible online environment. The IMS Global Learning Consortium (2004) offers a detailed description of accessibility as the flexibility of the education environment and the availability of adequate alternative but equivalent content and activities. The IMS Global Consortium also stresses the vital role of the context and environment the user is in; therefore, accessible online learning environments adjust the user interface of the learning environment, and adjust the resources to match the needs and preferences of the users. The participant teachers in the oTPD-STEM program defined their user-friendly online environment as the one that was mobile-friendly with a familiar social networking platform. Both Facebook and WhatsApp satisfied the participant teachers' defined accessible online environment needs. This finding corresponds to Burns (2011) who described smart phones as the most promising technology for distance teacher education in developing countries. Interestingly, smart phone ownership exceeds computer ownership in Asia and Africa (International Telecommunications Union, 2011). More specifically, So (2012) reported that in Pakistan, the number of mobile phone subscriptions per 100 inhabitants is 59.2 whereas only 13 percent of households have a computer. This trend is unlike the US where computers still hold a significant place. Another reason that supports the notion of a mobile-friendly oTPD-STEM program in a Pakistani context is the cheaper and more widespread access to the Internet through mobile phone networks, which overcomes the persistent issue of power outages and low bandwidth. As Shaheen shared during her second interview, "…my mobile phone is active 24/7 and I usually check every notification getting more thinking time for activity posted on Facebook or responding to WhatsApp text".

Comfortable Online Interactions

All of the participant teachers saw themselves as intermediate to proficient online users as reported in the pre-survey "All about me," whereas after participation in oTPD-STEM 1.0, it was discovered that some of their online abilities ranged from very basic to moderate. The naïve ability to generate online interactions made the participant teachers' online experience uncomfortable in oTPD-STEM 1.0 which had been built as a structured, modular, course-like format on Moodle using Web 2.0 tools such as VideoAnt, Flipgrid, VoiceThread, and discussion forums. Redesigning oTPD-STEM 1.0 to oTPD-STEM was a result of the researcher-practitioner partnership. Through the continual partnership within the oTPD-STEM program, the participant teachers voiced their needs and preferences, which allowed customization of the online professional development to meet their specific needs. The customization of oTPD-STEM allowed participant teachers to act as collaborators and co-constructors/co-designers (Wang & Hannafin, 2005) of the online TPD environment that resulted in a greater understanding of "learning ecology" (Cobb et al., 2003 p.9). The details are shared in Chapter 4. The major design decisions for oTPD-STEM 2.0 were supported by existing evidence of the potential positive benefits of using Facebook and WhatsApp for teaching and learning, especially in an Asian context. According to Susilo's (2014) findings, Facebook offers pedagogical, social and technological affordances that allow for posting announcements, sharing ideas, and resources, and implementing online discussions.

Asynchronous and Synchronous Interaction

The effectiveness of oTPD STEM increased once it was hosted on a free, online, social platform, Facebook, which originated as a social networking platform and with the development of a community of practice using the free, cross-platform mobile messaging app, WhatsApp. Participant teachers did not rely on Facebook for discussions. Instead, Pakistani participant teachers heavily relied on WhatsApp for asking questions, discussing, sharing audio, video and photo data. Susilo's (2014) study also indicated this dual benefit of WhatsApp mediated learning by highlighting the possibility of engaging learners synchronously along with the affordances for asynchronous communication that allows for the retrievability of messages posted even if the user is offline or outside network coverage. Therefore, Facebook and WhatsApp leveraged the participant teachers with both asynchronous (anytime, anywhere) and synchronous (realtime) interactions. Another synchronous interaction was leveraged by Skype which allowed the participant teachers to reflect on their experiences and for different components of integration of STEM along with reflection on the instructional design component of the oTPD-STEM program. Skype offered a virtual audio connection to each team so they could also humanize their experiences along with reflecting on their oTPD-STEM experiences.

This blended use of asynchronous and synchronous interactions gradually evolved through continuous formative evaluation and finally by a summative evaluation. The researcher and participant teachers were engaged in continual reflection about the instructional design of the oTPD-STEM program and the STEM focused content of the program. This aspect aligns the findings of design-based oTPD-STEM with Cobb, et al.'s (2003) idea of calling design studies as "test beds of innovation." oTPD-STEM finally emerged as a blended teacher professional development environment that was supported by the innovative use of existing free, online environments primarily used for social networking. McKenney and Reeves (2012) have also highlighted the researcher-practitioner partnership using Wagner's description of "social design of research projects" (p. 17). Similarly the design-based oTPD-STEM program evolved within communities of practice and was molded by the goals of those who pursued it (i.e., the researcher and practitioners). Moreover, the blended model of this online teacher professional development program supported building a community of practice among the participant teachers due to affordances of the online PD, such as the proximity to practice, ability to reflect on proximal practice, ability to move at the participants' own pace (Fishman et al., 2013). and acknowledging the unique learning needs in the Pakistani "context" (Dede at al., 2009; Squire, 2006).

Summary

In this chapter the researcher identified the instructional design components of the oTPD-STEM program, which facilitated the participant teachers' understanding of STEM integration. It also demonstrates ways to overcome the constraints by sharing the exploration, implementation, and evaluation of the oTPD-STEM program. An accessible and comfortable online environment, asynchronous and synchronous interactions and building a community of practice through the blended use of asynchronous and synchronous interactions on Facebook, WhatsApp, and Skype allowed the participant teachers to explore integration of STEM.

The following chapter presents the case study of team Purifiers, a team of three of the in-service elementary teachers who were developing their understanding of integration of STEM in an online teacher professional development program. The case of team Purifiers allows the readers to closely view the evolution of the participant teachers' understanding of STEM integration throughout their participation in the oTPD-STEM program. Chapter IV also examines the case of team Purifiers to discuss the ways in which the participant teachers developed their ideas about STEM integration within the oTPD-STEM program. The concluding chapter returns to the discussion on design-based decisions for oTPD and on the evolution of understanding STEM integration using the case of team Purifiers. It also outlines the implications for both the theory and practice of design-based online teacher professional development.

Chapter IV: Exploration of STEM within oTPD-STEM

Chapter IV presents three participant teachers' exploration of STEM within the oTPD-STEM program using a single exploratory case study design. Following the detailed description of the design-based oTPD-STEM program, and answering research question 1 in the previous chapter, this chapter describes how three participant teachers' views of integration of STEM evolved throughout their exploration of the new idea of STEM integration in the Pakistani oTPD-STEM program. This chapter intends to answer research questions 2 and 3 by using the case of Team Purifiers, the team consisting of elementary school teachers Fatima, Shaheen, and Tania.

> How do Pakistani teachers' views of integration of STEM evolve throughout their participation in the oTPD-STEM program? **(research question 2)**
>
> How do teachers explore the idea of STEM integration through their participation in an online teacher professional development program? **(research question 3)**

Chapter IV presents the case of Team Purifiers in five main sections. The first section describes the research design for this exploratory case study. The second section consists of a narrative description of the case of Team Purifiers. This case narrative introduces readers to the three members of Team Purifiers and their collaborative interactions as they progressed through the oTPD-STEM program. The third section describes the three main themes that illustrate Team Purifiers' evolution as they worked through issues to understand STEM integration in response to research question 2. The fourth section presents the three main themes that emerged in answering research question 3. The final section summarizes the case of Team Purifiers using a visual model illustrating the ways Team Purifiers explored the oTPD-STEM program to develop their understanding of STEM integration for their Pakistani context.

Research Design

Research Design - Exploratory Case Study

The exploratory nature of this study calls for a case study with inductive analysis as the analytic approach. This single, embedded case study explored three participant teachers in Team Purifiers' developing understanding of STEM integration throughout the oTPD STEM program. Due to the lack of prior research on this innovative education reform in a Pakistani context, the goal of this study is inductive theory building. The goal of using a single, embedded case study is to describe the distinguishing features of the process of understanding STEM integration for three Pakistani inservice elementary teachers. Another important point of significance for using a single, embedded case study is that this research method is theory-driven, grounded in real-world contexts, and provides in-depth exploration of the case. This approach is also aligned with the overarching design-based research used in the oTPD-STEM program.

Given that design-based research (DBR) lacks argumentative language that links the research questions to real data, the data to analysis, and the analysis to the final claims and assertions (Kelly, 2004), a case study approach addresses this shortcoming. It allows the researcher to connect the phenomenon with the context by examining multiple data sources to construct evidence-based theoretical propositions (Yin, 2013). Clarifying the argumentative language of DBR through a case study approach has allowed the researcher to focus on both the process by which the participant teachers grappled with STEM integration, and the means by which the participant teachers' understanding was supported. Consequently, this in-depth case led to one of the goals of this design-based study: theory generation (Wang and Hannafin, 2005).

Research Setting: Pakistan

This study was carried out in Lahore, Pakistan. The context of this case is CVE, a private elementary school of the larger school, CVSS. Three of the eight participant teachers who worked together as Team Purifiers in the oTPD-STEM program represent the case in this chapter. The details about CVE and its curricular context are described in detail in Chapter III.

Participant Selection

As described in Chapter III, of the 16 participant teachers from CVSS who initially participated in the oTPD-STEM program, only eight participant teachers completed the entire oTPD-STEM program. All eight participants belonged to the same school and worked in teams of teachers teaching at the grade 4 and 5 levels. There were three teams in all: two teams with three participants each and one team with only two participants. Due to the flexible and self-paced nature of this oTPD-STEM study, all eight participants adjusted their participation based on their own time constraints. Considering the researchers' time constraints in attempting to complete a DBR study as a dissertation, the three participants of Team Purifiers were purposively sampled from the eight in-service teachers because they were the first team to complete the oTPD-STEM program.

Patton (2002) has supported the purposive sampling strategy as a process of "selecting information-rich cases for in-depth study. Information-rich cases are those from which one can learn a great deal about issues of central importance to the purpose of inquiry" (p.230). Team Purifiers was chosen for the case study since they responded to the oTPD-STEM program earlier than the other two teams. In addition to their early response, Team Purifiers actively contributed as co-designers throughout the oTPD-STEM program. Although these teachers were selected for this case study primarily due to their early participation as a key selection criterion, these participant teachers chosen offer thorough and pertinent data to answer research questions 2 and 3. Team Purifiers included Fatima, Shaheen, and Tania (see Table 4.1). Fatima is a grade 5 mathematics teacher with 20 years of teaching experience. Fatima is a generalist teacher by qualification and taught science for the first time during academic year 2015-2016 when this study was conducted. Shaheen is a generalist teacher with 12 years of experience. She has primarily taught mathematics at the elementary and middle grades. Like Fatima, Shaheen also taught science for the first time to grade 5 during the course of this study. Tania who has a diploma in information technology is a grade 5 computer science teacher with 14 years of teaching experience.

Table 4.1

Team Purifiers' participant demographics.

Name	Qualification	School	Teaching Subject	Grade	Years of Teaching Experience	Participated in oTPD-STEM
Fatima	M.Ed., B.A.	CVE	Math, Science	5	20	1.0 & 2.0
Shaheen	M.Ed., BSc.	CVE	Science, Math	5	12	1.0 & 2.0
Tania	M.A. Urdu, DIT	CVE	Computer Science	5	14	1.0 & 2.0

Research Timeline and Data Collection

A hallmark of a case study is the use of multiple data sources, a strategy that also enhances data credibility (Patton, 1990; Yin, 2003). Each data source is one piece of the "puzzle," with each piece contributing to the researcher's understanding of the whole phenomenon. This convergence adds strength to the findings as the various strands of data are braided together to promote a greater understanding of the case. Multiple data collection methods were employed for each research question to yield a more robust data set. Three interviews (a total of 450 minutes), four reflective learning team conversations (a total of 280 minutes) and three STEM perception responses were the primary sources of data. Several artifacts were generated throughout the oTPD-STEM program, including Facebook group chats, WhatsApp texts, photos, videos, voice chats, and audio and video clips when Team Purifiers was planning and rehearsing the mini-STEM unit (see Table 4.2).

Interviews. Three semi-structured interviews were conducted. The first semi-structured, face-to-face interview, as discussed in Chapter III (Appendix 3.2), was conducted in person at the start of this study in March 2015. In the interview, the researcher asked the participant teachers to describe several aspects of their understanding and experiences for each discipline (science, technology, engineering and mathematics). In particular, they were asked to (1) elaborate on integration; (2) describe their understanding of integration of science, technology, engineering, and mathematics; (3) share their experiences of integration of science, mathematics, or any other discipline; and (4) share the strengths and challenges of integrating different disciplines. Interviews ranged from 15-25 minutes depending upon the participants' response

Table 4.2

Research timeline for the case of Team Purifiers

<table>
<tr><th rowspan="2">Timeline</th><th rowspan="2" colspan="2">Activities in oTPD-STEM</th><th colspan="4">Data Collected</th></tr>
<tr><th>Interviews</th><th>STEM Perception Response</th><th>Reflective Learning Team Conversations (RLTC)</th><th>Artifacts</th></tr>
<tr><td>March 2015</td><td colspan="2">Prior to oTPD-STEM 1.0</td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td>April 2015</td><td colspan="2">-</td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>May-June 2015</td><td colspan="2">oTPD-STEM 1.0</td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>July-August 2015</td><td colspan="2">-</td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td>Sep.-Oct. 2015</td><td rowspan="8">oTPD - STEM 2.0</td><td><u>Practice Unit</u></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>Early Nov.2015</td><td>-</td><td></td><td>X</td><td></td><td>X</td></tr>
<tr><td>Mid Nov.-Dec. 2015</td><td><u>Exemplar STEM unit:</u> Evidence-Based Reasoning</td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>Jan. 2016</td><td><u>Exemplar STEM unit:</u> Storyboarding</td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>Feb. 2016</td><td rowspan="2"><u>Exemplar STEM unit:</u> Engineering Design Challenge</td><td>X</td><td></td><td>RLTC-1</td><td>X</td></tr>
<tr><td>March 2016</td><td></td><td>X</td><td>RLTC-2</td><td>X</td></tr>
<tr><td>April 2016</td><td rowspan="2">Mini-STEM Unit</td><td></td><td></td><td>RLTC-3</td><td>X</td></tr>
<tr><td>May 2016</td><td></td><td>X</td><td>RLTC-4</td><td>X</td></tr>
</table>

The second interview occurred after the completion of oTPD STEM 1.0 from July-August 2015. Interviews were conducted through Skype and each participant teacher was asked to reflect on their oTPD 1.0 experience and share ideas for further exploration of STEM integration in oTPD-STEM 2.0 (Appendix 4.1). Finally, the third Skype interview was conducted in February 2016 when participant teachers were about to begin their first engineering design challenge in oTPD-STEM 2.0 (Appendix 4.2). This final interview aimed to gain insights into the participant teachers' experiences during oTPD-STEM 2.0, while also exploring barriers and support that they encountered during the process of learning about integration of STEM.

STEM perception response. The STEM perception response asked the participant teachers to describe their views of integration of STEM. The participants were asked to submit their STEM perception responses at three times throughout the oTPD-STEM program. The first STEM perception response was collected in November 2015 before the exemplar STEM unit began. The second STEM perception response was gathered in March 2016 after Team Purifiers completed their implementation of the exemplar STEM unit. Finally, the third STEM perception response was collected after the team designed their mini-STEM unit in May 2016.

Reflective learning team conversations (RLTC). Team Purifiers took part in reflective learning team conversations 1 and 2 while they were enacting the exemplar STEM unit in February and March 2016. They participated in reflective learning team conversations 3 and 4 after they had completed the exemplar STEM unit and were designing their own mini-STEM units in April and May 2016. Each reflective learning conversation lasted about an hour in a Skype phone conference call. These reflective learning conversations focused on the integration of STEM, engineering design challenges, scientific inquiry, and perspectives of integration of STEM. Before each reflective learning conversation, pre-conversation tasks were posted on the Facebook group site and included video tutorials explaining the research grounding of the topic of conversation supported by some exemplar YouTube videos. (Appendix 4.3)

Artifacts produced in the oTPD-STEM program. Various artifacts were produced throughout the oTPD-STEM program, including (1) participants' written responses to Facebook group posts; (2) WhatsApp texts, photos and videos of their implementation of the STEM-integrated exemplar unit in the classroom; (3) audio conversations about designing the mini-STEM unit; and (4) videos showing Team Purifiers' engineering design challenge of the mini-STEM unit. Finally, the researcher's reflective log that was completed throughout the oTPD-STEM program was used as a secondary data source.

Data Analysis

Inductive analysis was used to analyze the data. Inductive analysis refers to approaches that use detailed readings of raw data to derive concepts, themes, or a model through the researcher's interpretations from the raw data. This description of inductive analysis is consistent with Strauss and Corbin's (1998) description where "the researcher begins with an area of study and allows the theory to emerge from the data" (p.12). The primary purpose of the inductive analysis is to allow research findings to emerge from frequent, dominant, or significant themes inherent in raw data without the restraints imposed by structured methodologies.

Transcription from Roman Urdu to translation into English. The primary data sources of Team Purifiers were interviews (a total of 450 minutes) and reflective learning conversations (a total of 280 minutes). The researcher conducted the interviews in the local Urdu language. She made this decision based on the participant teachers' stated preferences given in the pre-survey. However, there were many English words used during the interviews and conversations. For the translation methods, the researcher first listened to the audio recordings to become familiar with the data and later transcribed one thirty-minute bilingual interview as a model sample for the transcriber who was a graduate student at a public university in Pakistan. The researcher referred to Halai (2007) for making use of bilingual audio data. The data was first transcribed in Roman Urdu (Urdu written with English/Roman letters). The transcriber highlighted the words that were spoken in English and underlined the words that were English words but have become part of the Urdu language. To decide which English words are now part of Urdu, an Urdu dictionary "Ferozul Lughat" was used. Once the Roman Urdu transcription was completed, the researcher read the transcribed word files and listened to the corresponding audio files for errors, omissions, or improperly transcribed words. After detailed counterchecks of the Roman Urdu transcription, the researcher selected chunks of the Roman Urdu transcribed data containing focused conversations for translation into English. For this step, special consideration was taken for transliteration (i.e., replacing the words of one language with the words of another because an exact translation is not available). The researcher asked the transcriber to follow this transliteration by giving the closest meaning in brackets. The final transcript was 210 single-spaced pages. The researcher carefully read the transcripts, frequently confirming with the original audio recordings.

Inductive coding. The researcher used QSR NVivo 11®, a research software program for qualitative research. The researcher imported the transcribed primary data into QSR NVivo 11® and approached analysis through continuous coding process. Analysis started with line-by-line coding of the transcribed data, which Strauss and Corbin (1998) categorizes as open coding. After the initial coding, some codes decayed while others flourished, raising the need to break down the codes into sub-codes. Later, the researcher rearranged the codes into themes and sub-themes. The researcher used axial coding to make conceptual connections between a theme and subtheme. By going through Strauss and Corbin's (1998) selective coding, an integrative process of selecting each core theme and systematically relating it to subthemes was done. This led to the final part of the analysis that includes core themes and conclusion drawing. Six themes emerged for the case analysis of the three participant teachers which allowed the researcher to describe the case of Team Purifiers. As shown in Table 4.3, these themes are (1) use of context, (2) centrality of science, (3) engineering seems distant, (4) reflective practitioner partnership, (5) integration of practices before STEM, and (6) factors influencing implementation of integration of STEM. A detailed description of the themes and visual model illustrating the case of Team Purifiers is included later in this chapter.

Ethical consideration. The researcher followed her home university's Institutional Review Board (IRB) guidelines to protect the rights of the participants and to conduct the research in a fair and equitable manner. In this study, the researcher provided all of the participants with a consent form (Appendix 3.1) describing the details of the study and participation expectations. The participants were also encouraged to ask the researcher questions for further clarification. Furthermore, the participants were told that they had the right to withdraw from the research at any time throughout the study. They were also told that participation in the study was voluntary and there was no possible risk to the participants in this study. Initially, the participants agreed to participate without any monetary benefit, but later in order to honor the time commitment of the participants, a small honorarium along with a certificate of participation (which had been promised from the beginning) were given to the participant teachers who completed the entire oTPD-STEM program.

Table 4.3

An overview of themes and sub-themes

Themes	Subthemes
Use of context	From broader context to local context Connecting local context to content Context for real-world connections
Centrality of science	Science is central Science and real-world application Mathematics as a support to science Technology as a tool for learning science
Engineering seems distant	Planning resources Coordination with peers Engineering design process not significant Seems like a science project
Reflective practitioner partnership	Teamwork among teachers Collaborative reflections on integration of STEM Model-enact-reflect cycle
Integration of scientific practices before STEM	Tension between teacher and student centered pedagogies Understanding practices of science
Factors influencing implementation of integration of STEM	Curriculum as an impediment Principal-teacher cooperation Parents-teacher interactions

Validity and reliability. Accounting for validity and reliability is the most prominent concern in qualitative research. Creswell (2009) considers qualitative validity as the basis for determining if the findings are accurate from the standpoint of the researcher, the participants, and the readers. To ensure internal validity, the researcher employed a combination of multiple validity strategies: triangulation, impartial peer reviews involving three impartial researchers, and using a prolonged amount of time to examine the data. The first two interviews and reflective learning team conversations of Team Purifiers were triangulated. Two of the researchers disagreed on one category and two subcategories. After mutual agreement was reached, the disputed subcategories were merged as a single subcategory (i.e., centrality of science) due to their close similarity. Subsequently, the category was reworded to bring out its richer meaning (i.e., factors influencing implementation of integration of STEM). Moreover, the researcher ensured interpretive validation by sharing the analysis of the study with the three participants of Team Purifiers and receiving their input on how the researcher portrayed their original thoughts. Creswell (2009) also explained that reliability of a qualitative study includes an examination of the stability or consistency of responses. To increase the reliability of this study, the researcher documented all of the procedures involved throughout this study and also provided details about all of the design decisions for the readers.

Case Narrative for Team Purifiers

Teachers' Profiles

Before presenting the analysis of the case of Team Purifiers, it is of considerable significance to view each individual teacher's profile to understand their interaction in the oTPD-STEM program as a team. Fatima's, Shaheen's, and Tania's profiles below depict their distinct characteristics. Later, as the case of this team of three teachers is presented, each participant teacher's unique contribution is noted to show how they developed a shared understanding of integration of STEM.

Fatima's profile. Fatima was teaching science and mathematics to grade 5 at CVE. Fatima was a very organized and devoted teacher. She had completed a B.Ed. in Science Education and a M.Ed. in Teacher Education preparing her as an elementary generalist. Fatima had been teaching mathematics to grades 4 and 5 for eighteen years, but in the previous year, she started teaching science to grade 5.With the exception of her first year of teaching, all of her teaching was at CVE which was situated within the larger school, CVSS.

In addition to teaching science and mathematics to grade 5, Fatima was the grade 5 coordinator. As a teacher, Fatima spent around eight hours weekly teaching science and mathematics and two hours teaching other subjects. In her coordinator role, Fatima spent four hours in meetings with other teachers to work on issues related to curriculum planning, reflecting on the learning needs of students, and making remedial plans to support learning of all students. She also spent eight hours doing work related to teaching science and mathematics such as coordination, notebook checking, and grading assessment papers. Fatima also spent around two hours at school or home doing miscellaneous school-related activities such as planning for curricular and co-curricular activities.

Fatima attributed who she was as a teacher to the guidance of her parents and had very fond memories of her own schooling. In the following excerpt, Fatima described her own schooling experiences and her journey of becoming a teacher:

> I have very fond memories of my school life. All my schooling is from a missionary school. This school offered co-education till grade 5. Later I remember girls and boys studied exclusively. I had always admired my math, chemistry and English teachers. I fell in love with math due to Mrs. Wasif, my math teacher. Mrs. Wasif used to teach us math with great care and love. I do not

> recall if I ever wanted to be a teacher but I remember when I was in high school I used to teach a boy, Ajmal, who was our maid's son. Our maid was a widow and used to be very happy when her son used to learn different new stuff from me. Ajmal was a very bright boy. I used to enjoy teaching him. I taught him for about three years. The most proud moment for me was when Ajmal got double promotion from grade 1 to 3. I think I had this spark for teaching, but I never realized it until later in life. After graduating, I didn't teach but once my own kids stated school, I started teaching, as this was the only job where I could be back home with my kids. After joining this profession, I truly felt obligated to teach students with all honesty and with emphasis on understanding the concepts and improved learning. I consider it my mission to pass on to our future generation not only the knowledge and skills but also the attitudes and behaviors. (WhatsApp audio response, April 2015)

Shaheen's profile. Shaheen was a lively and committed teacher. At the time of the study, Shaheen was teaching grade 5 science and mathematics at CVE. Shaheen completed her B.S. and M.Ed. with a mathematics focus. She had taught mathematics at grade 5 through 7 for over twelve years at three different private schools and had started teaching grade 5 science at CVE the year this study was conducted. Shaheen's teaching time was split into five hours of mathematics, two and a half hours of science, and an hour and twenty minutes in computer science. Shaheen usually spent an hour planning for each of the three subjects. In addition, she worked on other curricular and co-curricular activities for about three hours a week at school and around two hours at home each week.

Shaheen recalled her memories from her growing up years in school, and shared who she was and how she became a teacher. Shaheen said:

> Right now, if I look back at myself as a student, I was a quite a shy person … having no confidence, I used to have lots of ideas but because of lack of courage and confidence, these ideas used to stay unexpressed. I remained unaware of my strengths for a long time. I attribute all the strength in my personality to my parents, family members, friends and most of all my students. My students used to challenge my hidden potential. I found teaching was a self-discovery for my own self. I am still very sensitive but am confident to face people. (WhatsApp audio response, April 2015)

Shaheen also reflected back on her own school experiences and mentioned names of people who had influenced her life. In her WhatsApp audio response, Shaheen shared:

> My schooling is from an Armed Forces public school system. The organized and disciplined environment provided me with wonderful experiences. I had such great teachers and true friends from that time. I took most of the inspiration from my mathematics teacher Sir Shahid and my English teacher Miss Gufrana. Both these teachers were very gentle human beings (may Allah be kind to them). I remember… I was an average student till elementary grades. Eventually, by looking at my friends and with motivation from my teachers, I started improving. I have been a very hardworking and eager student. This brought a lot of change in me. (WhatsApp audio response, April 2015)

Shaheen also recounted how she entered into teaching. She openly described her initial reason for joining the profession and then reflected on why she decided to continue teaching. In her WhatsApp audio response, Shaheen stated that she knew she was an introvert: “My family was convinced that by becoming a teacher I would be able to overcome my fears by communicating with my students and later I would be at ease with adults too.” She also saw herself becoming more confident as she grew in her teaching abilities. Later, Shaheen talked about her teaching beliefs that “equally stress upon the content knowledge, the behavioral and moral values.” Shaheen shared the need to integrate religious teachings into contemporary teachings to address the current distress in society. She stated,

> My personal experiences of 10-15 years [of teaching] have made me realize that our education system needs to emphasize developing social skills…. skills that are required for interacting with others in an ethical way, handling situations in society. I see teachings of Islam could bring this awareness in our students, by motivating students to follow teachings of Islam in all their actions. (WhatsApp audio response, April 2015)

Tania's profile. Tania's highest degree is a masters in Urdu but due to her diploma in information technology (DIT), she mostly taught computer science throughout her thirteen years of teaching at CVE. At the time of this study, Tania was teaching grade 5 computer science and science. Tania was a very active and thoughtful teacher participant in this study.

Tania's entry described her teaching career as accidental. She had always wanted to work in the field of information technology but instead she started teaching in elementary school and described how she was happy about this accident. She shared:

> To be honest with you…I accidently became a teacher. After I did my diploma in computer science, I wanted to work at a software house but ended up being a teacher. Initially, I did not like teaching at all, but eventually I ended up liking it. I have learnt so much through teaching kids and talking to my peers. I began teaching the way I was taught but when I used to talk to my peers and observe their activity-based teaching, it gave me a new way to help students learn with understanding. I realized through activities that not only do kids learn better but activity-based teaching was way more interesting than the traditional rigid way. (WhatsApp Audio response, April 2015)

Tania shared her own schooling experience as very different from what she was practicing with her students:

> When I was in school… all the focus was on rote learning. We were simply asked to memorize content. We used to memorize question answers. I even remember memorizing essays at the high school level…we used to learn blah blah… essays and we used to get some essay topic from that list during exams. Even during my college days, I hardly remember any activity-based learning kind of tasks. We used to take notes of lectures and maybe consult a few reference books. (WhatsApp Audio response, April 2015)

Tania also talked about her teaching philosophy. She favored teaching for lifelong learning gains unlike the traditional method of teaching that relied mainly on rote learning. Having experienced rote learning, Tania wanted to facilitate students' learning. Tania stated, "I want my students to learn knowledge that prepares them for lifelong learning. I want kids to be able to learn… research in order to make their learning useful for them forever." (WhatsApp audio response, April 2015)

Team Purifiers in the oTPD-STEM Program

Fatima, Shaheen, and Tania decided to work together as a team soon after the first face-to-face meeting with the researcher. Shaheen took the lead in communicating the contact information, team member details, and subject expertise of all the participants from CVE. Team Purifiers nominated Shaheen as their team leader.

Getting started with oTPD-STEM 1.0. Despite the technology challenges described in Chapter III, Team Purifiers interacted with the tasks posted on the site for oTPD-STEM 1.0. In this chapter, the researcher focuses on the exploration and developing the teachers' understanding of STEM integration and of STEM within the oTPD-STEM program.

Module 1 began with developing a common understanding of best teaching practices for science and introducing the participant teachers to integration of STEM as an educational approach. Several tasks were designed to engage participant teachers in the introductory module. The participant teachers were asked to discuss how the local context informed the teaching practices and to share how local problems provided a context for learning. Team Purifiers asked clarifying questions about the nature of the local problems in the STEM curriculum.

> Shaheen: What is meant by "Problems in your neighborhood"?
> Fatima: I think it is about issues like pollution, climate change, global warming…
> Researcher: These are big issues, for this task focus on local problems like e.g., lack of a drainage system in Canal town, main road.
> (WhatsApp text chat, May 2015)

Following these clarification statements, Team Purifiers completed the classroom activity that was meant to connect research with practice. This allowed the participant teachers to use the idea of the local context discussed in module 1, by asking students to think about problems that existed around them and that needed immediate attention. They were asked to list them and then start thinking about possible solutions. Shaheen submitted the written student data showing how students identified problems in their neighborhoods in Lahore (see Figure 4.1).

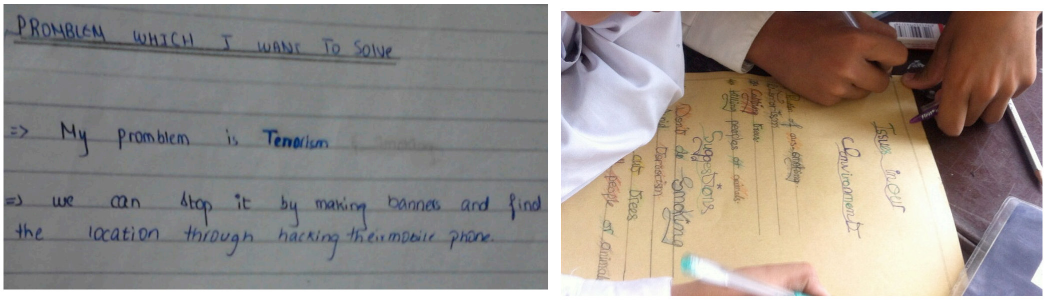


Figure 4.1. Pictures showing students work about problems in their neighborhoods

The team shared students' identified problems such as electricity outages, lack of clean drinking water, too much traffic in Lahore, water drainage issues in the Cantonment area, and danger of terrorism. Fatima and Shaheen contributed some video data where students talked about their local problems and how they wanted to solve those problems. The team was fascinated by the students' ideas and interest in their local environment. Shaheen later shared why they were surprised with the student-generated ideas in her second interview in July 2015 by explaining, "I had never had a chance to generate students' ideas about the problems around them… There is hardly any time to relate science to actual lives of students." Similarly, Fatima explained the same point as, "We always connect science concepts with the global problems but seeing students notice their local problems and trying to make their simple connections with the big problems really surprised me."

Team Purifiers also tried a different strategy to complete Module 2. Each member read all the tasks except the STEM curriculum unit called "Save the sea birds." Shaheen studied this curriculum unit and later had a share-out meeting with Tania and Fatima where they fleshed out the key features of the unit using the framework of integration of STEM (Moore et al., 2014). Team Purifiers thought the unit “Save the sea birds” required many special materials and new pedagogies especially involving online collaborative tools for students, and most importantly, they discussed how it needed to be adapted for grade 5. Shaheen expressed her excitement and apprehension about implementing the STEM unit in her classroom. In her WhatsApp text chat, Shaheen commented, “I am impressed by how the unit connects each piece together …but such specialized materials are required to do this unit and also students are working on some online platform.” Later during the same chat, Tania shared, “[The unit] ‘Save the sea birds’ is huge. I don’t see us ever doing it.” Fatima responded, “This unit is for middle school. It’s not easy to take this unit and bring it into our classrooms without detailed planning.” Fatima emphasized that this unit was designed for grades 6-8 and it would require detailed adaptation to bring it down to the level of grade 5. Team Purifiers grappled with how to use the unit “Save the sea birds” because this extensive curricular resource included the involvement of many materials, use of online collaborative tools that students were not familiar with, and the need to adapt the unit to grade 5 level. These challenges discouraged the participant teachers from using it in their classrooms.

Beginning of oTPD-STEM 2.0 with a practice curriculum unit. As part of the design of oTPD STEM 2.0, the teams shared some specific content areas that could be used to implement the unit in their classrooms that would be aligned with the prescribed school curriculum. The practice unit on *Food, Nutrition and Health* adapted from Simcox's (2012) *Health and Nutrition Toolkit* was posted as Post 1 on the Facebook group. Team Purifiers was asked to apply the model-enact-reflect strategy (discussed in Chapter II) to parse the curricular resource, rehearse it within the team, incorporate the unit in their classrooms, and reflect on their experiences with the research-based STEM curriculum unit. Team Purifiers collaborated to flesh out the unit. Shaheen and Fatima exchanged clarification messages about the context of obesity and overweight among children in Pakistan.

> Fatima: Are we actually saying Children's Hospital?
> Shaheen: I see no problem in that!
> Fatima: We are creating a story, right?
> Researcher: Yes, we can say that…this is your context for exploring the whole unit.
> (WhatsApp text chat, September 2015)

Before implementing the practice unit, Team Purifiers made an adaptation where they added an informational talk by a nutritionist. The following chat highlights the team's decision while planning for the practice unit.

> Shaheen: Let's start by recalling food groups, the hand activity, and then introduce the context.
> Tania: Are we doing it exactly as it is planned?
> Fatima: Yes, I think we can follow it completely.
> Shaheen: How about if we ask the nutritionist from Children's Hospital to give a talk to students about this issue?"
> Fatima: That's a good idea. I can arrange it. My brother's friend is a doctor at Children's Hospital.
> Tania: Agreed…Thanks Farah for taking this responsibility!
> (WhatsApp text chat, September 2015)

Teachers had to adapt the task that asked a pediatrician/nutritionist to give a motivational talk on the benefits of healthy eating and living habits because of security concerns in the school. Shaheen prepared a questionnaire that asked for information from the pediatrician/nutritionist about the benefits of healthy eating and living habits. Shaheen and Fatima assigned students to ask any practicing doctor/nutritionist/pediatrician to fill in the health questionnaire and later the students had to present their collected data in the classroom. Team Purifiers' conversations excerpts showing their interactions for exploring the practice unit were

Fatima: I am not sure if students will come this week.
Researcher: What happened?
Shaheen: Serious security threats to schools in Lahore.
Researcher: I am so sorry to hear that.
Tania: Is our doctor coming?
Fatima: No… we won't get permission to invite someone outside the system (due to security reasons).
Shaheen: Let's think of something else then…
Tania: Maybe we could ask students to interview some doctor they know of?
Shaheen: Yes…I can make a questionnaire and students can use it (to get information from doctors).
(WhatsApp text chat, September 2015)

During the implementation of the practice unit, Team Purifiers found the icebreaker activity related to science knowledge about food groups to be very effective as they found students referring to their hands as they talked later about the significance of food groups. Shaheen pointed out, "The hands, palm and fingers activity was very effective to recall the five main food groups"

Team Purifiers also shared their challenges with the claim, evidence, and explanation task. This task required students to analyze data on obesity trends among 10-14 year old Pakistani children and making a claim from the data. Team Purifiers found it difficult to make claims using the available evidence. Fatima shared that she routinely ended up framing the question instead of asking students to make a claim.

Evidence-based reasoning was also new for the students. Fatima, in particular, was very concerned about the tasks requiring the students to make a claim based on the evidence found in the data. However, Tania and Fatima shared that their students were highly engaged in the online worldwide and countrywide data for overweight and obese children. Team Purifiers believed that this online interactive data helped the students view the obesity and overweight trend by age. Fatima said that this task was very challenging for her students, "Yes, this task was difficult but with practice students will learn." Mostly, students were not able to justify their claims based on their evidence. Shaheen and Tania considered it a matter of doing such as task for the first time and aspired to see an increase in students' ability to use claim, evidence, and explanation with more practice

> Shaheen: Students took a lot of time to understand how to make claims.
> Tania: It was their first time. I hope next time students will feel better.
> (WhatsApp text chat, October 2016)

In the culminating engineering design challenge, the Children's Hospital and the Institute of Child Care Health in Lahore invited the grade 5 students to help raise awareness among local children and youth about developing healthy eating habits and healthy lifestyles (see Figure 4.2). The challenge was to propose a cost-effective, time-efficient way to spread awareness in the community about obesity and overweight by offering visible health gains. The team was generally happy with the performance of their students in the challenge task, but, at the same time, they voiced concern about the chaos created in the classroom due to students working in small teams. Team Purifiers shared these thoughts later in their reflective learning team conversation, “Working in teams means losing control and routine discipline.”

Students were encouraged to use the claims that they had made by exploring data on obesity in Pakistan and the world. The teachers were happy to see the students’ solutions. The student teams suggested various ways to spread awareness with evidence-based remedial measures to reduce obesity and overweight including (1) sending group text messages to a large number of people using WhatsApp, (2) sending a group email to people, (3) using a Facebook post shared with all their contacts, (4) creating an ad for television and especially airing it on the Cartoon Network and Disney Channel, and (5) distributing awareness brochures to children in schools. Each student team shared their solution and talked about why they chose the particular media, the design of the awareness message, and the awareness message offering an evidence-based remedy to the problem. Team Purifiers reported that their students did not need to redesign the task since they were already behind in their scheduled plan because of lost teaching time during the school closure due to the security threat.

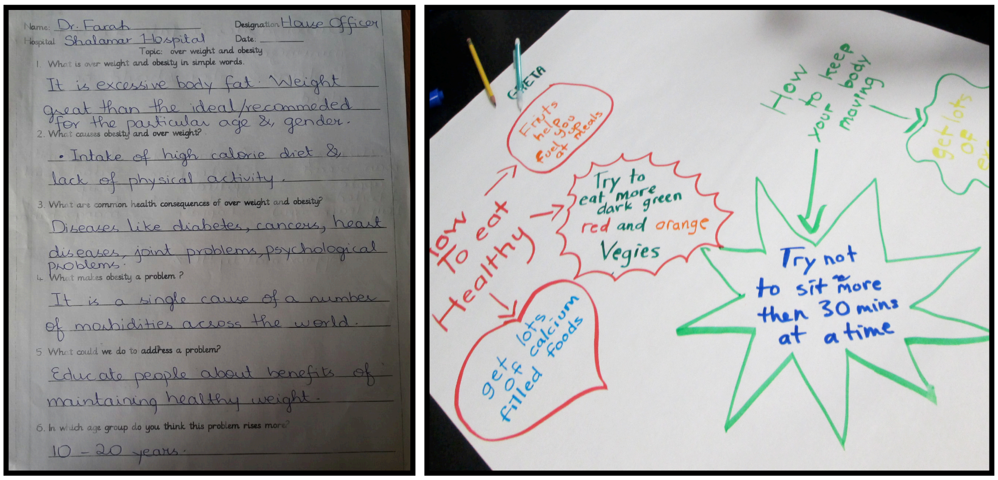


Figure 4.2. WhatsApp Photos: L-R Student’s work showing a survey done with a doctor, and sample work of a team showing their “Obesity and Overweight Awareness Message.”

Building STEM conceptions with the exemplar STEM unit. Many interesting conversations occurred while clarifying the first STEM perception response task. Detailed evidence of Team Purifiers’ STEM conceptions are shared below in the discussion of research question 2. Fatima started the conversation thread by inquiring about the STEM perception. Shaheen and Tania also joined this conversation along with the researcher. The following WhatsApp text thread depicts Team Purifiers’ naïve understanding of STEM as they had to begin the conversation by asking about what STEM perception meant:

Fatima: What do you mean by STEM perception?

Researcher: It is your understanding of STEM integration
the way you look at this idea...
Whatever comes in your mind when you hear or read STEM integration ☺
Does that make sense to you?
Fatima: Do you want us to write or send it as a WhatsApp voice message?
Researcher: Either way will work...or what works best for you!
Shaheen: Would it also include the reflections from the previous modules done?
Researcher: This is about what you think of STEM integration at this point. If your understanding developed from these two modules …yes, why not? ☺
Tania: So it is about how I see STEM?
Researcher: Yes!
Tania: Ok 👍

(WhatsApp comments, November 2016)

The second content area that teachers had requested as a focus for STEM integration in oTPD STEM 2.0 was heat and heat transfer. Thus, the researcher adapted another unit as an exemplar STEM unit, called “Cool It,” and shared it on the Facebook group site. The first task posted for this unit was an introduction to the context of a malaria outbreak in Pakistan and the most recent preventive measure of the malaria vaccine. Data was provided for the students to analyze and practice the claim, evidence, and explanation model that was first introduced in the practice unit on food. The participant teachers were asked to use the model-enact-reflect pedagogy to understand the exemplar STEM unit. The team explored the task collaboratively. All three participant teachers used the data and made claims using that data and discussed it as a team on a working Saturday at their school. Together, they practiced enough to use this task of making claims and using the claim, evidence, and explanation model in the classroom.

Shaheen reported that students were equally challenged by the enactment of making claims using the given data on malaria in Pakistan. Fatima shared how their continuous practice of evidence-based claims in their regular classroom teaching helped students improve responses to reasoning questions. The excerpt below shows Fatima's and Tania's reflections on this task, emphasizing how practice helped Team Purifiers understand this task and what made them decide to continue this kind of task in their classrooms beyond the oTPD-STEM program:

> Fatima: Evidence-based reasoning is a new thing. All of us modeled the claim, evidence, and explanation (CEE) task. This really helped us to move on and take it into our classroom. Later we looked at students' responses and decided to use it as a remedy for developing reasoning skills of our grade 5 [students].
>
> Tania: This can also be helpful as a routine practice for us teachers to improve our teaching practices regardless of this oTPD-STEM program.
>
> (Reflective Learning Team Conversation 1, February 2016)

The second task in the exemplar STEM unit was to first learn the technique of storyboarding and using the evidence-based claims technique to create a storyboard to show how vaccines work. The team decided to divide different pieces of the storyboard among the three of them and strategically jigsaw this task. Team Purifiers first practiced the jigsaw pieces of the storyboarding task within their team. Later, Shaheen implemented this task in her science lesson and did the storyboard about vaccines with six teams of 4-5 students each. Shaheen found that the students were excited about creating their individual parts and then making a storyboard collectively. In contrast, Shaheen was worried about the chaos created in the classroom due to working in teams. Shaheen also shared her concern over keeping all of the teams engaged in the task. Shaheen shared, "Though I made teams of mixed abilities…some of my weak students were unable to keep up the pace of their team." Tania also contributed to this task by showing a short video clip about vaccines prior to Shaheen's lesson in the computer lab.

Team Purifiers was challenged with the third task of the exemplar STEM unit. This task involved the science content of "heat transfer," "types of heat transfer," and "conductors and insulators." Although all of the team members, especially Shaheen, really liked the task, this task of scientific inquiry required several materials that they had to arrange well before the classroom implementation. The three of them had to first model it in order to anticipate the probable difficulties for students. This delayed both their practice within their team and later implementation in their classroom. Eventually, Fatima, Shaheen, and Tania again split up the task into smaller chunks and practiced it as a team to discuss the concept of heat transfer with each other. Tania did problem 1 (i.e., to investigate which material keeps a juice can cold for a longer time) and problem 2 (i.e., investigate which spoon–plastic or metal–would keep an ice cube cold). Fatima did problem 2 and problem 3 (i.e., investigate hot and cold water transfer to heat when they are mixed together) and Shaheen did problem 3 and problem 4 (i.e., investigate how heat transfers from a heat lamp to the hand and how this transfer of heat can be stopped using the right kind of material). After discussing the details with their team members, Tania implemented problem 1 in the classroom, Fatima implemented problem 2 and Shaheen completed the task by carrying out investigations for problems 3 and 4. Shaheen concluded the task by asking students to put all four problems and their findings together to present their work as one storyboard and do a gallery walk through to see the other teams' storyboards. Team Purifiers shared how they were challenged by the constraints of gathering the materials and doing the student-centered inquiry activities. While sharing their implementation experience, Team Purifiers shared their difficulty of keeping the activities focused on inquiry rather than mostly implementing this task as a teacher-centered activity. These tensions are shared later in detail under the theme of "integration of science practices before STEM."

After providing extensive content background, Fatima and Shaheen co-taught the engineering design challenge of designing a vaccine cooler to safely carry vaccines from one place to another. This task consumed considerable time and energy. Again, Fatima, Shaheen, and Tania gathered materials using their personal resources which included mainly items from their own homes or from friends and peer teachers. The team practiced the engineering design challenge and shared their reflections among the team members. Tania introduced the task to students in the computer lab and showed them two short video clips about existing vaccine cooler designs and their limitations. She later engaged her students in brainstorming about possible design solutions. Shaheen and Fatima decided to co-teach the engineering design challenge lesson. They noticed that students did not enjoy drawing models of their design solutions, but most of them liked talking about their ideas. At the same time, students were extremely excited when they were testing their designs. Shaheen and Fatima also shared their disappointment when none of the student teams could see any significant difference in temperature drop while testing their prototype of their vaccine coolers. Students repeated their observations to note the temperature change but found no change in temperature. Thus, the teachers did not ask them to redesign their prototype, as they could not find any reason to do this step. During the reflective team conversations, the team attributed the students' inability to notice any change in temperature to two factors: the cold weather of almost 0°C (32°F), and the time limitation for the pre- and post-observation of temperature. The following excerpt illustrates Team Purifiers' experience with the engineering design challenge task.

> Shaheen: Students enjoyed the testing part of the engineering design the most. They carefully noted the pre- and post-mass of the ice cube and its temperature.
>
> Fatima: When they didn't see any clear difference…students were disappointed. But then we discussed what might be the reasons and then a few of the students were so interested in this challenge, they said we would repeat this challenge in May to find out the results.
>
> Researcher: Did the students try to redesign their prototype?
>
> Fatima: As we had seen, it was not due to the design of the prototype, so we decided not to ask students to redesign.
>
> (Reflective Learning Team Conversation 2, March 2016)

The second STEM perception response was collected after the completion of the exemplar STEM unit, "Cool It." Fatima, Shaheen, and Tania explained their understanding of STEM integration using science, mathematics, and technology. They were unsure about the place of engineering within CVE. They also attributed this understanding to practicing the STEM exemplar unit among the three teachers, and also to its implementation in the classroom. The following excerpts from Team Purifiers' STEM perception response show how they viewed STEM:

> Science is the base. Then comes mathematics like volume, weight, and price. Technology helps in collecting and showing data. Engineering can help to design models using science and mathematics. But real-world application weaves all disciplines together.
> (Fatima's STEM perception response 2, March 2016)

> Science is the main focus while mathematics and technology are thoughtfully integrated to make the connection with context and content.
> (Shaheen's STEM perception response 2, March 2016)

> We integrate science with different subjects depending on the content and context chosen for STEM. We involve technology to get all the information. Mathematics comes in with data. We can see engineering but how? Still not clear.
> (Tania's STEM perception response 2, March 2016)

Designing and practicing their own mini-STEM unit. Team Purifiers developed their initial ideas for their own mini-STEM unit while sharing their thoughts in the reflective learning team conversations. Team Purifiers was engaged in periodic reflective learning team conversations to help them process their learning during oTPD-STEM 2.0. The goal of these reflective learning team conversations was to connect theory and practice of integration of STEM, the engineering design process, and scientific inquiry. Each conversation was supported with video resources as a pre-conversation task to help them get started with a specific reflective team conversation. The first three reflective learning team conversations occurred in consecutive order allowing them to think, talk, and plan their own mini-STEM unit. Reflective learning team conversation 1 was in February 2016 and focused on the integration of STEM. The generated conversations were significant as they provided reflections on Team Purifiers' experiences in the oTPD-STEM program and also allowed them to access other team members' understanding of STEM integration while they talked about research on integration of STEM. During this conversation, they also discussed the STEM framework (Moore et al., 2014). Three important points from these conversations emerged. First, it was evident that Team Purifiers viewed the role of context as "glue." Second, Team Purifiers' views of "technology as a support for science" became very evident. The third significant was that Team Purifiers' views of the engineering design process was an "extension activity" that extends beyond science and mathematics learning. Three snippets from reflective learning team conversation 1 below present their views on the context of STEM, role of technology, and engineering in STEM:

> Shaheen: I have found that embedding STEM in a local context acts like glue that helps to connect different disciplines together.
> Researcher: What do you mean by "glue"?
> Shaheen: Well…in the STEM exemplar unit the context of malaria became the basis for science content of vaccination, mathematical understanding

of the trend of malaria outbreak in Pakistan and addressing the problem of transporting vaccines safely to patients by engineering a vaccine cooler required understanding of another science concept−heat and heat transfer.
(Reflective Learning Team Conversation 1, February 2016)

Tania: The vaccines video clip was very helpful.
Researcher: Were you able to show it to students?
Shaheen: Yes, the short and quick background information of vaccines prepared students to understand the context of heat unit.
Fatima: This is how technology makes science learning easier.
(Reflective Learning Team Conversation 1, February 2016)

Shaheen: I know…my worry is if it takes that long how would we continue doing integrated lessons in the future?
Fatima: It (engineering) extends students' learning of science and mathematics. As with all other extension activities the engineering design challenge could be shortened or omitted totally depending on students' preparedness or available time to do justice with the engineering part.
(Reflective Learning Team Conversation 1, February 2016)

Reflective learning team conversation 2 was in March 2016, as Team Purifiers was completing the exemplar STEM unit. This conversation focused around connecting research and practice of the engineering design process. This conversation allowed Team Purifiers to clarify two main ideas. First, Team Purifiers recognized their prevalent teacher-centered pedagogies and talked about ways that helped them to make this shift to a student-centered pedagogy. Second, Team Purifiers' frail understanding of the engineering design process became evident. The following two snippets from the second reflective learning team conversation depicts Team Purifiers' understanding of inquiry-led tasks and the engineering design process:

> Shaheen: The storyboarding task on heat was interesting but was very lengthy. I felt if I could demonstrate some of those activities myself in class, that would save on time and serve the purpose too.
> (Reflective Learning Team Conversation 2, March 2016)

> Shaheen: We did not ask students to do "explore, plan, and redesign" in the engineering design process; we simply let students design a vaccine cooler by designing and testing.
> Researcher: Do you think only these two steps will allow students to develop the most creative and effective design solution?
> Fatima: Yes, students already knew the problem and context so they simply designed and tested their prototype.
> (Reflective Learning Team Conversation 2, March 2016)

Reflective learning team conversation 3 was in April 2016 when the team was planning their own mini-STEM unit. This conversation revolved around scientific inquiry. During this conversation, Team Purifiers extended their ideas about a student-centered pedagogy and discussed evidence-based reasoning as their starting point towards scientific inquiry.

> Fatima: At first, I did not understand the claim, evidence, and explanation model, but now I feel this has shown me how to engage students to carry out small activities to create real data and make a claim using that data.
> Tania: We are so used to rushing through content to complete the syllabus that we hardly give time to students to get engaged in such inquiries.
> Researcher: I agree, time is a universal constraint.
> Shaheen: Honestly, we hardly get any time to think about how to improve our practice to let students learn better.
> (Reflective Learning Team Conversation 3, April 2016)

The team also shared their ideas about their mini-STEM unit, as detailed in the following section. The team started with various ideas with science content of "human body systems," "mixtures and solutions," and "light and shadow." While discussing ideas for their mini-STEM unit, Team Purifiers came up with an idea to design a water purification system. The excerpt below illustrates Team Purifiers' plan for their mini-STEM unit. The excerpt also illustrates how Team Purifiers reflected on how to gather lessons learned from the implementation of the STEM exemplar unit and again reflected on ways to connect those lessons for planning their mini-STEM unit.

Shaheen: … so let's design a unit on a water purification system.
Researcher: okay…great!
Shaheen: I'll do the science exploration practice and ask students to share their findings in the form of a storyboard
Fatima: and the context is our very own problem at school - the water filter we have in school…due to increasing number of students are unable to purify water for all students. So the school administration has challenged fifth-graders to figure out the most efficient, cost effective way to purify water... students have to design a water filter for the school!
Researcher: Great idea! Have you thought about the budget? How much money is the school administration willing to spend on this project?
Fatima: We have not discussed this point. I think now that we have decided the science content and the context for the unit, we will figure out the mathematics, technology, and engineering part of our unit.
Tania: How about if can provide students with a few options for materials to use for designing the water filtration system for their school.
Shaheen: I was thinking about the list of materials and the total budget we had for designing the vaccine cooler…we can use it as a sample and plan a budget for students for designing the water purification system for our school.

Fatima: So we can evaluate the water filtration on the criteria of cost effectiveness and overall effectiveness of the water purification design.
(Reflective Learning Team Conversation 3, April 2016)

Team Purifiers discussed what they wanted to do for designing their mini-STEM unit. Fatima, Shaheen, and Tania collaboratively came up with this mini-STEM unit as the final task of the oTPD-STEM program. They modeled their mini-STEM unit within their team and shared the video of testing their design.

Reflective learning team conversation 4 was the final conversation held in May 2016 to discuss the perceptions of integration of STEM that allowed a connection with the theory and practice embedded in Team Purifiers' local context. The final reflective learning team conversation was about the different prevalent STEM perceptions as indicated by research. Team Purifiers together reflected back on their experiences within the oTPD-STEM program and framed their conversations around their school, classroom, and students. This conversation allowed Team Purifiers to consolidate their understanding about integration of STEM, share their personal perceptions about STEM, and reflect on how the integration of STEM allowed them to make changes in their teaching pedagogy. The following conversation excerpt depicts team Purifies' reflections on Bybee's nine models and how they viewed them within their school context:

Researcher: As you have seen Bybee's models of STEM integration, would you please share how you see those models?
Fatima: I liked the integrated discipline model that talks about connecting four disciplines as a unit. I see we can do at least STM easily.

Shaheen: Yes, Fatima. This integrated discipline model with science, technology, and engineering seems quite doable. I liked it best due to its possible application in our school.

Tania: I kept on thinking about combining the three disciplines to make a new discipline model. I was wondering if STEM is implemented as a separate subject along with separate subjects like science, mathematics, etc.
(Reflective Learning Team Conversation 4, May 2016)

Team Purifiers reflected on their experience throughout the oTPD-STEM program and shared what ideas impacted them. The following excerpt shows their reflection on their teaching practices:

Researcher: Before I proceed ahead …how do you see your current method of teaching? How would you describe it?

Fatima: After a full years' experience of oTPD-STEM, I have observed that my teaching style has changed and is more focused towards experiential teaching. The change in me is also very visible. The class has become more interactive, and when students ask me for support, I guide them to find out their solution using different resources that they can consult. I feel myself that now I am teaching differently, forcing myself to facilitate students' learning by not providing the answer but leading them to find the answer themselves.

Researcher: What would you say, Shaheen?

Shaheen: Definitely… a similar case with me! There are changes in my teaching. Previously, we were relying only on theory but now all the concepts we have taught are practical and integrated with technology. And hands-on activities are being carried out for every topic that is performed in the school. Small models and practical (strategies) are routine. They are very useful because they leave an impact on the minds of the students that help them in their exams too.

Researcher: Tania, can you also shed some light on it?

Tania: Well…I am not teaching science but what I see is that previously there was rote learning. Science was only taught by rote learning.

> Now, it is integrated, practical (activities) are done and technology is involved.
> (Reflective Learning Team Conversation 4, May 2016)

The final STEM perception response was in May 2016. Team Purifiers assigned the central position to science, with mathematics and technology integration as a support to science that is embedded in a particular context. The team was able to define the role of engineering within CVE. Team Purifiers named the engineering design challenges “extension activities” that may be linked to science, technology, and mathematics throughout the year. As a result, the students’ projects could be presented during the annual exhibition and scientist/engineer day. One response summarized the participants’ views:

> I view STEM as having science as the main reference point. Both mathematics and technology support science to strengthen the application of these subjects in the real-world context. Engineering can extend students’ knowledge of science, mathematics, and technology by building models.
> (Fatima’s STEM perception response 3, May 2016)

> Science is central in STEM where the context allows mathematics and technology to support science in relation to a real context. I see engineering in STEM as an advanced level of application of science, mathematics, and technology that can only happen twice or thrice an academic year.
> (Shaheen’s STEM perception response 3, May 2016)

> STEM is mainly about making science learning strong. Mathematics and technology both integrate into science while engineering is very demanding in terms of the engineering design process, time, and materials. We need to think hard to integrate engineering in our school context. We can connect engineering with science exhibition projects.
> (Tania’s STEM perception response 3, May 2016)

Themes Answering Research Question 2

RQ 2. How do Pakistani teachers' views of integration of STEM evolve throughout their participation in the oTPD-STEM program?

Bringing together a team of elementary teachers and asking them to engage in an online teacher professional development program to understand a novel approach of integration of STEM challenged their prior views about the four disciplines. In response to research question 2, this section discusses how Team Purifiers' views of integration of STEM evolved during their participation in the professional development. Team Purifier's views of integration of STEM evolved based on their understanding of the use of a local context to connect with the STEM disciplines, their perceived centrality of science, and their idea that engineering is distant (see Table 4.4). Team Purifiers' views of integration of STEM for their Pakistani context evolved from SM/S.T.M. to Stm---(e) based on their experiences throughout the oTPD STEM program.

Table 4.4

An overview of the themes and sub-themes showing Team Purifiers' views on integration of STEM

Themes	Subthemes
Use of Context	From a broader context to local context Connecting the local context to content Context for real-world connections
Centrality of Science	Science is central Science and real-world application Mathematics as a support to science Technology as a tool for learning science
Engineering seems distant	Planning resources and coordination with peers Engineering design process not significant Seems like a science project

Prior to participation in the oTPD STEM program, the team was most familiar with science-mathematics integration. Fatima talked about integration as ”sometimes naturally present and at other times we have to make effort to link the subjects…For example, *graphs* can be easily linked with *weather*−a topic from science.” Shaheen commented on the existing experience of integration in a limited way. She said, “We do integrate but not very often due to time limitation…The only place for integration is when students already have the content knowledge, then we can merge science with mathematics.” Tania mostly used integration while teaching computer studies. Tania narrated an example of integration of mathematics and computer studies: “When I was teaching MS Excel, I asked students to make a flight schedule using mathematics to calculate time durations.” Tania expressed her perception of integration slightly differently. Tania discussed felt her lack of necessary expertise to integrate across disciplines and explained her difficulties as, “When I try to integrate some subject content using small video clips or online resources, oftentimes it becomes hard for me to help students understand the content of a subject in which I am not an expert.”

Team Purifiers’ views of the integration of science, technology, engineering, and mathematics about adapting it into the Pakistani context were based on how Fatima, Shaheen, and Tania viewed each of the four disciplines. Their understanding of STEM was also based on how Team Purifiers viewed the four disciplines as being complementary. Pragmatic reasons also impacted how Team Purifiers evolved in their views of integration of STEM. Three themes support Team Purifiers' understanding of STEM: (1) use of context, (2) centrality of science, and (3) engineering seems to have distant support.

Use of Context

Team Purifiers started participating in oTPD-STEM 1.0 with the idea of big global issues like climate change and global warming. Before the beginning of Module 1, the teachers were asked to contribute by identifying problems from their local environment. They all suggested grand challenges around the world. When they asked the same question to their students while doing the classroom activity of Module 1, it surprised the team when students identified problems in their own neighborhoods. The teachers were amazed at the list of problems that their students suggested. Fatima, Shaheen, and Tania shared their surprise through WhatsApp texts:

> Shaheen: The students came up with real problems around them…I was surprised when I saw terrorism at the top of their list.
> Tania: It is indeed a problem that needs to be addressed.
> Shaheen: I agree. The students identified electricity outages as another big problem.
> Fatima: The students are very observant…My class also pointed out issues like lack of clean drinking water, too much traffic in Lahore, and the water drainage issue in Cantonment area.
> (WhatsApp text, June 2015)

Gradually, Team Purifiers experienced the use of local context challenges first in the practice unit and later in the STEM exemplar unit. During the practice unit, Fatima, Shaheen, and Tania realized that the students were fully engaged in the problem of obesity and overweight among Pakistani children. Team Purifiers also found that the connection was very powerful between the local context and the broader worldwide trend of obesity and overweight among children ages 10-14. Later, when Team Purifiers implemented the STEM exemplar unit, they again noticed how the context of a malaria outbreak in Lahore allowed students to quickly connect to a similar problem of a dengue fever outbreak. The team also noticed that examining the problem at the global level made it "real learning" as Shaheen described in her third interview in February 2016. Team Purifiers was able to see the context in a connected way that acknowledges the local problems and connects those local problems to greater global issues. Later, Team Purifiers gained more experience with a complete practice unit and in the middle of the exemplar STEM unit. During the first reflective learning team conversation, Fatima, Shaheen and Tania highlighted the vital role of context in STEM and how the local context stimulates students' understanding of the greater global contexts. The excerpt below provides a sample of Team Purifiers' conversation:

> Shaheen: I have found that embedding STEM in a local context acts like glue that helps to connect different disciplines together.
>
> Researcher: What do you mean by "glue"?
>
> Shaheen: Well…in the STEM exemplar unit the context of malaria became the basis for science content of vaccinations, mathematical understanding of the trend of a malaria outbreak in Pakistan, and addressing the problem of transporting vaccines safely to patients by engineering a vaccine cooler [all of which] required understanding of another science concept, heat and heat transfer.
>
> Fatima: Yes, context glued the disciplines to make it easily understandable.

Tania: Usually this real-world connection is missing in our routine teaching. That's why usually students are unable to make sense of why we learn so many things in separate subjects.
(Reflective Learning Team Conversation 1, February 2016)

The use of context became a critical component of Team Purifiers' understanding of STEM. Although Team Purifiers considered context as the "glue" for the integration of STEM, they found that creating an authentic context for STEM was very challenging.

While discussing ideas for the design of a mini-STEM unit, Team Purifiers started with an idea (human body systems), then shifted to another idea (solutions), and finally decided on the third idea (water purification) due to the challenge of creating an authentic context. The following excerpt provides insights into the complexity of creating a real-world context for integration of STEM:

Fatima: We are thinking of human body systems as the main science content.
Researcher: Say more …
Shaheen: For engaging students in motivating context, we have chosen spinal cord injury and will ask students to expand epidural stimulation research as a possible cure. We have asked students to do claim, evidence, and explanation about the effectiveness of epidural stimulation. We will engage students in research about the content topic. Alongside, kids will make presentations on the research they are doing. For the math part, we are using the facts about human body like the number of bones, number of cartilages, etc. for doing the math content.
Researcher: So what's the problem you pose in your context of spinal cord injury or what would be your engineering design challenge, and how will your mathematics content support this STEM unit?
Fatima: We will create the context of road accidents in Lahore leading to spinal cord injury, and the students will research the solution.

Researcher: Think of a problem that exists in your context that can encourage students to reach a possible solution through an engineering design process. Can you try posing the problem again?
Fatima: The problem would be spinal cord injury and students will find a solution through research.
Tania: We could use the data for road accidents.
Researcher: How is this context helping you to create a STEM integrated unit?
Shaheen: Maybe we can think of another context…
Researcher: Let's recall our exemplar STEM unit and see what our context, problem, content was and then the engineering design challenge. (Reflective Learning Team Conversation 2, March 2016)

In this conversation, the teachers were trying to create a context around the science content about the human body system that was already in their curriculum. Team Purifiers was also trying to create a context from a local problem of road accidents in Lahore that caused serious spinal cord injuries. They then grappled with creating an engineering design challenge that could be used with their local problem of increasing spinal cord injuries due to road accidents.

Centrality of Science

Team Purifiers viewed science as the central position in STEM. The team talked about the centrality of science throughout their oTPD-STEM experience. During the practice round, Team Purifiers had a quick WhatsApp text chat that illustrated how the team viewed science in STEM.

Tania: Food groups have never been so interesting.
Fatima: I have just started it but have the same feeling.
Shaheen: I felt my science lesson was very impactful. The science content is directly used in the real problem of obesity and overweight among

children, and also the data helped to understand the intensity of the problem.

Tania: Integration helped to make science powerful.
(WhatsApp text, October 2015)

Team Purifiers not only commented on the central position of science in STEM but also stressed the significance of real-world connections to strengthen science by exploring a problem that involved the use of science content supported by data. Tania, Shaheen, and Fatima developed their shared view about the central position of science in STEM and agreed that mathematics supported science. They looked at mathematics as supporting science and not as the main part of STEM, like science. The team discussed how science has a "natural tendency" to integrate mathematics, technology, or engineering in the conversation below:

Tania: Mainly we focus on science.

Shaheen: Tania is right. Since day one, I have noted the main focus was based on science. We started off with mathematics in science through data representation and analysis. Maybe there is a possibility that science has a natural tendency to integrate mathematics, technology, or engineering depending on the level of the students.
(Reflective Learning Team Conversations 4, May 2016)

Team Purifiers saw science as the central component of STEM when they were implementing the engineering design challenge. They particularly recognized the central role of science when they were trying to design a vaccine cooler that could keep malaria vaccines safe, even when the power supply was unreliable. They noticed that choosing the right kind of material to build the vaccine was vital. Then, understanding all of the possible heat transfer methods was critical in making their vaccine cooler heat proof. The conversation below illustrates how Team Purifiers strongly viewed science as a pivotal component of STEM.

> Shaheen: We realized while modeling the engineering design challenge that without knowing the science behind making a vaccine cooler, we won't be able to proceed with the challenge itself. Our understanding was confirmed when we implemented the challenge in our classroom. Students were asking me if this material is a better insulator or that material would not allow conduction.
>
> Fatima: This makes me think the engineering design challenge is more of an extension activity that extends students' science understanding through application.
>
> (Reflective Learning Team Conversation 2, March 2016)

As Team Purifiers participated in the oTPD-STEM program, they considered technology as a tool to learn computer skills using content from another discipline. However, Team Purifiers' view about technology changed to technology as a tool for learning science. Tania explained how students had started exploring technology as a tool for learning science.

> Tania: Students are now very interested in making presentations. They want to learn about science using resource websites and share their findings in making PowerPoint presentations.
>
> Researcher: So you want to say that students' understanding is improving by connecting science and technology disciplines?
>
> Tania: Yes, now kids are trying to make connections and figure out for themselves where to find relevant information and how they want to present the content from different disciplines. I guide students with the tools and the kids decide about the content and how they want to lay out the information or present their research.
>
> (Reflective Learning Team Conversation 1, February 2016)

Another way to use technology to support science learning was through the use of short video clips. The team talked about the usefulness of showing short video clips describing the science concept or activity with a follow-up discussion to engage students. All of their efforts tended to focus on making science learning effective for students by either using mathematics as a support subject or using technology. When describing their thoughts about integration of STEM while implementing the STEM exemplar unit, Fatima, Shaheen, and Tania shared their reflective thoughts in their team's WhatsApp group.

Shaheen: The vaccines video clip was to the point.
Fatima: The right size!
Researcher: Were you able to show it to students?
Tania: Yes, the short and quick background info for vaccine…did it today!
Shaheen: Yes, it made science learning easier.
Fatima: The other one about levels of claims was useful too…I was able to clarify my own claims.
Shaheen: It is hard to go to the advanced level of argumentation.
(WhatsApp conversation, January 2016)

The team continued to share the usefulness of using technology to facilitate science. Fatima's WhatsApp text chat with the researcher indicates how they continued using short video clips as a quick means to provide background knowledge or reinforce a concept that can readily get students engaged in a hands-on activity. In one of the WhatsApp text chats between Fatima and the researcher below, Fatima discussed how the use of video clips was a time-effective way to reinforce the concept of states of matter that led to the follow-up work of illustrating the water cycle as student presentations.

Researcher: Can you please share an example of how you used video clips?
Fatima: For the lesson on states of matter, we showed a video clip on the movement of particles.
Researcher: What was the follow-up activity?
Fatima: Students made presentations on the water cycle to show the states of matter.
(WhatsApp text chat, April 2016)

Team Purifiers' views about the role of technology are important to understand how they viewed integration of STEM. The findings shared so far clearly illustrate how Team Purifiers focused on science as the core discipline in STEM, with mathematics and technology as supporting components that are embedded into the Pakistani local problems to develop real world connections.

Engineering Seems Distant

Team Purifier actively implemented the exemplar STEM unit. However, they struggled with the engineering design challenge for both cognitive and pragmatic reasons. First, the teachers' understanding of the engineering design process was limited. Team Purifiers was detered by the number of design elements involved in the engineering design process and did not see the value of this iterative design process. Team Purifiers considered the multi-step engineering design process as lengthy and time consuming. In particular, they did not understand the value of providing a purposeful structure of define, explore, plan, design, test, and redesign that would lead the students to develop creative problem solving skills and promote communication skills and teamwork (Roehrig et al., 2012). The team suggested that they would prefer to treat the engineering design challenge as a science investigation where they could set up materials and make observations instead of following the iterative design cycle of defining, exploring the problem, planning, designing and testing the prototype, and finally redesigning the prototype. Reflective learning team conversation 1 illustrates Team Purifiers' limited understanding of the engineering design process.

> Researcher: How do you feel about the engineering design process?
>
> Shaheen: The engineering design process is quite lengthy. I wonder if we could just design and test!
>
> Fatima: I was already thinking the same, Shaheen. We are already implementing the STEM unit in an extra class that is specially arranged for us. It would take us ages to complete the engineering design challenge this way.
>
> Shaheen: I don't think we need to follow all the steps of the engineering design process. We can let the students design a vaccine cooler by simply designing and testing.
>
> Researcher: Do you think these two steps will allow students to develop the most creative and effective design solution?
>
> Fatima: Yes, students were already introduced to the problem and context, so they can easily start designing and then test their prototype.
> (Reflective Learning Team Conversation 1, February 2016)

Due to pragmatic restrictions of time and resources, Team Purifiers struggled to integrate engineering into their existing curriculum. They attempted to find an authentic place for engineering that could fit into their context. They found the engineering design to be an elaborate design process that required more time than a regular science lesson. They also recognized that it required many materials, which mainly relied on student-centered tasks and involved a lengthy, iterative process of the design cycle including room for failure.

> Researcher: Can you say more about the engineering design process?
> Shaheen: It is a stepwise process of designing projects that promote learning from failure that is very challenging.
> Researcher: What makes failure challenging?
> Shaheen: We never let students fail so how can we promote that idea?
> Tania: Another thing that I have noticed is this engineering process is very lengthy; I don't see how it can fit into a science lesson.
> Fatima: The engineering design is mainly student centered which will make it way lengthier!
> (Reflective Learning Team Conversation 2, 2016)

With all the complexities involved, the fact that engineering is not included in Team Purifiers' curriculum made it even harder for them to relate to. The following excerpt illustrates Tania's struggle to fit engineering into the school environment.

> Tania: In science, we can still relate mathematics and technology to any topic in our syllabus, but when it comes to engineering…it is hard to imagine where we can put it.
> Researcher: You are saying that science could be easily integrated with subjects like mathematics or technology. What about engineering?
> Tania: Science, mathematics, and technology are interrelated, but what is not present is engineering. We cannot see it as a subject. I think we can involve it by conducting exhibitions and a scientist day, and then we could at least see implementation of engineering.
> (Reflective Learning team Conversation 3, 2016)

Tania shared how she could not envision the place of engineering since it was not in the curriculum. Even though this excerpt was Tania's point of view, Fatima and

Shaheen shared similar thoughts about engineering. Shaheen shared in her final interview that “engineering looks distant from STM. There is no doubt that engineering has provided us a new way to help students extend their content knowledge but it (engineering) still looks foreign!” Thinking about STEM and finding a place for engineering was important for the team to understand the integration of STEM. Team Purifiers eventually identified a suitable place for engineering that could fit in their school context. They proposed connecting engineering with their two annual events: science exhibition and the scientist/engineer day. The team thought that linking the STEM projects with those events would be meaningful for students to keep them engaged in the projects throughout the year and finally to communicate and present their work to parents and outside visitors.

Again, the conversation shows how the team was working in a living environment where each component was tightly connected. To create space for a new subject, they had to make special arrangements. The teachers were closer to their own environment and were thinking of ways where they could make room for new ideas like the engineering design process within the set boundaries of their school environment. Team Purifiers viewed engineering as an extension of science, mathematics, and technology. Therefore, they considered the presence of engineering in STEM as an opportunity to enrich students’ concepts by helping them engage in the design process where the students could apply their science and mathematics knowledge and skills by creating a model or designing a project.

> Shaheen: I know…my worry is if it takes that long, how would we continue doing integrated lessons in the future?
> Fatima: It (engineering) extends students' learning of science and mathematics. As with all other extension activities, the engineering design challenge could be shortened or omitted totally depending on the students' preparedness or available time to do justice to the engineering part.
> (Reflective Learning Team Conversation 1, 2016)

At the end of the oTPD-STEM program, the Team Purifiers' conversation quoted above highlights their view of engineering in STEM and also discusses ways that could help them include the integration of STEM into their classrooms. The team had developed a vision of how they wanted to see the integration of STEM in their schools. They were clear about the significant role of science, mathematics and technology. They acknowledged that engineering was an opportunity for students to apply their knowledge of the content learned in other disciplines to design a model or project that could be displayed at their school's annual science exhibition and their annual scientist day. This conception of engineering means that engineering is limited to making projects or models and allowing students to share their integrated work with parents and other visitors during exhibitions.

Answer to RQ2: SM/S.T.M. to Stm----- (e)

Over the course of the oTPD-STEM program, Team Purifiers experienced the integration of STEM by testing the exemplar STEM unit within their team, in their classrooms, and also by noticing how students responded to the integration of STEM. Team Purifiers developed their views of the role of each discipline within STEM that contributed to their evolution in understanding of STEM. This subsequently led Team Purifiers to construct their own STEM model that was rooted in the context of CVE and their classrooms. The following summary describes how Team Purifiers' understanding of integration changed from SM/S.T.M. to their own concept of Stm-----(e) throughout the oTPD-STEM program (see Figure 4.3).

Practice unit	oTPD-STEM 2.0					
	Evidence-based reasoning	Story-boarding	Engineering design challenge		Mini STEM unit	
			RLTC-1	RLTC-2	RLTC-3	RLTC-4
Sep.-Oct. 2015	Nov.-Dec. 2015	Jan. 2016	Feb. 2016	March 2016	April 2016	May 2016

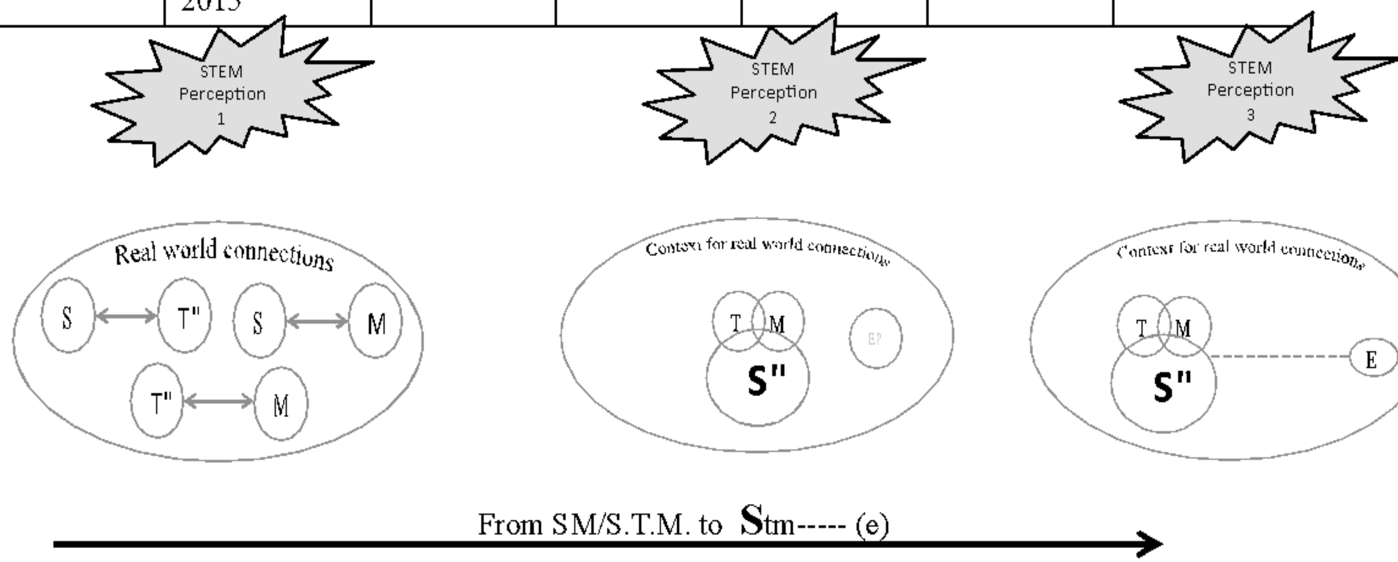


Figure 4.3. Timeline showing the evolution of Team Purifiers' understanding of STEM from SM/S.T.M. to Stm-----(e)

The initial STEM perceptions of Team Purifiers closely identified with Bybee's (2013) model of STEM that refers to coordination across the disciplines. The only difference in Team Purifiers' initial STEM model is that it reflected the coordination between two disciplines rather than Bybee's (2013) coordination among three or more disciplines. Team Purifiers' initial STEM model could also be explained using Vasquez et al.'s (2013) continuum of disciplinary through transdisciplinary approaches to the integration of STEM. Team Purifiers' initial STEM model was close to the multidisciplinary approach where concepts and skills are learned in separate disciplines but in reference to a common theme. In Team Purifiers' case, the common theme was real-world connections (see Figure 4.4).

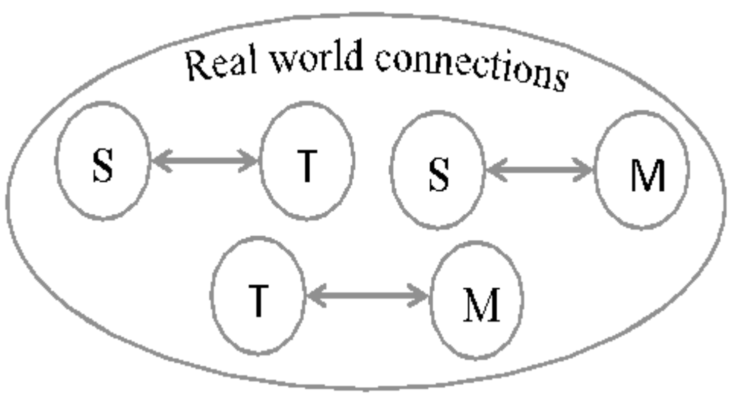


Figure 4.4. Team Purifiers' initial STEM model showing "coordination between disciplines"

In their second STEM perception response, Fatima, Shaheen, and Tania started to emphasize real-world connections, and over time they expanded on the importance of context in understanding the real-world connections. Fatima expressed her realization as follows: “Science is the base. Then comes mathematics like volume, weight, and price. Technology helps in collecting and showing data. Engineering can help to design models using science and mathematics. But real-world application weaves all disciplines together.” The team also stressed the centrality of science, “Science is the main focus while mathematics and technology are thoughtfully integrated to make connection with context and content.” However, they did not perceive the importance of engineering. Tania explained her STEM perception as, “We integrate science with different subjects depending on the content and context chosen for STEM. We involve technology to get all the information. Mathematics comes in with data. We can see engineering but how... still not clear” (see Figure 4.5).

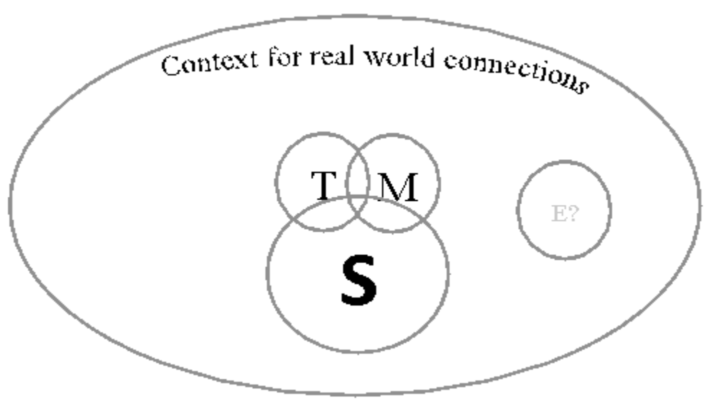


Figure 4.5. Team Purifiers’ intermediate STEM model showing their “interdisciplinary approach to STEM with science as the central discipline.”

Figure 4.5 illustrates Team Purifiers' intermediate STEM model where the interdisciplinary approach to STEM integration shows science as the central discipline with mathematics and technology integration strengthening science content and engineering as lacking a clear role. Working in a team and parsing the components of both practice and the exemplar STEM curricular unit allowed Fatima, Shaheen, and Tania to elaborate on their understanding of STEM integration and to reach this intermediate STEM model.

The final STEM model of Team Purifiers was inspired by their reflective conversations based on research on the integration of STEM combined with Fatima, Shaheen, and Tania's idea generation for the mini-STEM unit. Fatima again stressed the importance of context for STEM integration. Fatima expressed her STEM model as, "The science focus with mathematics and technology integration can bring out real-world connections while engineering can help students create models and projects for the annual science exhibition and the annual scientist day." Shaheen again pointed out the central place of science and explained, "Science is the foundation and the context helps to integrate mathematics, technology, and engineering. I think we can only carryout engineering to let students design models for the science exhibition." Finally, Tania described her final STEM perspective as, "STEM is basically about making learning of science meaningful for students. Technology, mathematics and engineering are all integrated to create real-world connections for students. Subjects are integrated depending on the need and feasibility for their implementation in school."

Team Purifiers' final STEM model as shown in Figure 4.6. depicts an interdisciplinary approach as described by Vasquez et al. (2013) with context-driven adaptations. Figure 4.6 represents the team's final model based on their first-hand experience with STEM integration in their classrooms. The team's experiences with STEM integration in a Pakistani context, students' responses to those experiences, and the team's reflection on their teaching evolved in the interdisciplinary model of STEM where science is central, technology and mathematics are integrated as minor support subjects, and engineering acts as an extension model-building activity.

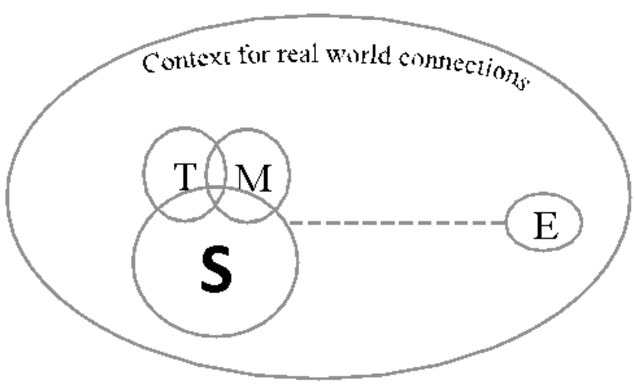


Figure 4.6. Team Purifiers' final STEM model.

Themes Answering Research Question 3

RQ 3. How Do Teachers Explore the Idea of STEM Integration through Their Participation in an Online Teacher Professional Development Program?

The oTPD-STEM program was designed and implemented to introduce the integration of STEM in Pakistan. It is significant for this study to examine the participation of Team Purifiers to discover how they explored the novel idea of integration of STEM in the oTPD-STEM program in their Pakistani context. The themes generated after inductive data analysis to provide a roadmap of how Team Purifiers explored the idea of the integration of STEM (see Table 4.5). The theme that most directly responds to research question 3 is a reflective practitioner partnership because it provides evidence of the strong teamwork among Fatima, Shaheen, and Tania despite their different disciplinary interests. This theme also provides details of Team Purifiers' collaborative reflections on the integration of STEM and how this practice helped the team explore a new approach to STEM in their own Pakistani context.

Table 4.5

An overview of theme, sub-themes and codes showing Team Purifiers' exploration of integration of STEM

Themes	Subthemes	Codes
Reflective practitioner partnership	Teamwork among teachers	Peer-teacher support Collaboration of ideas and resources Way to address time constraints STEM not an individual thing Making connections before implementation
	Collaborative reflections on integration of STEM	Reflecting backward and forward Learning from exemplar unit Learning from students' responses Learning from students' social interaction
	Model-enact-reflect cycle	Understanding by practicing and implementation Views based on student learning Experimenting with integration of disciplines
Integration of scientific practices before STEM	Tension between teacher and student-centered pedagogies	Routine teaching - less chaos Role shifting Assessing team work No time for inquiry Time-driven pedagogy
	Understanding practices of science	Learning by doing Evidence-based reasoning Connecting science with real-world mathematics is a natural connection in science Technology for obtaining, evaluating, and communicating science.
Factors influencing implementation of integration of STEM	Curriculum as an impediment	Balance between depth and breadth of content knowledge Curriculum lacks relevance Distant curriculum planner Inflexible curriculum Innovation as curriculum
	Principal-teacher cooperation	Support for PD Alternatives for teaching & learning Willing to listen
	Parent-teacher interactions	Satisfied if work prepares for tests Alarmed with change Willing to support Support students at home

The most significant of the three themes directly responding to research question 3 is the reflective practitioner partnership that illustrates the teamwork among Fatima, Shaheen and Tania even though they had different disciplinary interests. This theme also provides details of Team Purifiers' collaborative reflections on integration of STEM and how this practice helped the team explore a new approach for STEM in their own Pakistani context. The second theme, integration of practices of science before STEM, illustrates Team Purifiers' continuous tension between teacher- and student-centered pedagogies. It also describes how Team Purifiers started exploring the practices of science. The final theme, factors influencing implementation of integration of STEM, identifies the affordances and barriers that Team Purifiers faced while exploring the integration of STEM. This theme describes the curriculum as an impediment whereas it describes principal-teacher cooperation and parent-teacher interactions as supportive influences.

Reflective Practitioner Partnership

Team Purifiers worked together to understand STEM integration and gradually started noticing the value of teamwork and the significance of collaborative reflections on the integration of STEM. These two characteristic features–teamwork and collaborative reflections– allowed Team Purifiers to develop a reflective practitioner partnership which is fully supported by literature (Schön, 1983; York-Barr et al, 2006). The following detailed description of Team Purifiers' reflective practitioner partnership offers insights into Fatima's, Shaheen's. and Tania's exploration of the integration of STEM.

Teamwork among teachers. Teamwork became the greatest strength for Team Purifiers. Over the course of the oTPD-STEM program, Fatima, Shaheen, and Tania noticed how working as a team helped them in multiple ways. First, STEM was a very abstract idea, but working as a team provided a place to clarify their ideas about STEM. The following excerpt provides evidence of how Team Purifiers collectively explored the integration of STEM:

> Researcher: I hope that by now you all have become comfortable doing the STEM exemplar unit.
>
> Shaheen: Honestly speaking, we had no clue about the integration of STEM in the beginning, but now as we are implementing it; we understand it better.
>
> Fatima: Shaheen is right. We want to know more about this new idea so as we are implementing the STEM exemplar unit in our classrooms and seeing students' encouraging responses, we are liking it more.
>
> Researcher: What makes you think students' responses are encouraging?
>
> Fatima: Like …in our recent work, students have mostly benefited from the teamwork and created the assigned storyboard after collecting data.
>
> Tania: This is true for the three of us too!
>
> Researcher: What is that?
>
> Tania: Teamwork has helped us to discuss the oTPD-STEM activities and also share our classroom activities.
>
> Shaheen: Oh yes, we actually practiced some evidence-based reasoning tasks among our team so we know what we are doing in the classroom…This claim, evidence, explanation model was new for us. (Reflective Learning Team Conversation 1, February 2016)

Working as a team also allowed them to deconstruct a STEM unit into manageable parts which also helped them overcome the two biggest constraints: time and resources. Team Purifiers practiced the STEM exemplar activities in each unit to share their findings and observations with the team members before they tried to implement the activities in their classrooms for the first time. When Fatima was interviewed and asked to comment on how she prepared for the storyboard task in the STEM exemplar unit, she explained how the team collaboratively parsed the storyboard task. Each team member worked out their part in their own time and then gathered again to share their findings and observations on the task.

> Researcher: Hmmm… Next, I want you to reflect on the storyboard task that you did for unit "Cool-it" with the science content of types of heat transfer and some hands-on and mind-on activities. Tell me how did you find this task?
>
> Fatima: We divided this task among our team members. One of us took the heat insulator part, the other took the heat transfer and one of us took the remaining part of the task.
>
> Researcher: Right…
>
> Fatima: So, we did our part individually and then came back together with our findings and discussed it together… then presented it as a storyboard and sent it to you.
>
> (Interview 3, Fatima)

Team Purifiers chose to split the tasks posted on the oTPD-STEM site among the three team members. After working out their part, they met to discuss how they planned to implement that part in their classroom. Making adaptations or adjustments usually followed these conversations. The conversation below illustrates Team Purifiers' process of exploring the engineering design challenge in the STEM exemplar unit. This conversation not only describes Team Purifiers' strategy to cope with the constraints of time and resources but also highlights how much they valued their teamwork while exploring this novel approach.

> Shaheen: Before implementing the engineering design challenge, we discussed the whole challenge. We spent most of the time planning for the vaccine cooler.
> Tania: We looked at the materials and the budget. It would have been a total disaster if each one of us had implemented it on their own.
> Researcher: How come?
> Tania: Well…there were some important changes that we made…We modified the testing site for the vaccine cooler after trying out our designs.
> Fatima: The weather was really cold and thinking of our classroom temperature [classrooms are not heated], we had to use four 100W bulbs. Instead of a hotpot, we decided to use two-inch thick Styrofoam sheets to build a testing site.
> Shaheen: And then gathering all these materials individually would have been very difficult. We gathered things to create a collective materials' kit. (Reflective Learning Team Conversation 3, April 2016)

Finally, teamwork provided Team Purifiers with the peer support and also with disciplinary expertise in the form of team members with science, mathematics, and technology backgrounds. The team stayed motivated despite the involvement of challenges of multiple disciplines in the integration of STEM as they worked as a collaborative team who supported each other throughout the oTPD-STEM program. Team Purifiers acknowledged that the integration of STEM was not the work of single teacher. The following exchange between Tania and Fatima provides insights into how this team felt about teacher-teacher partnerships for the implementation of STEM in their school.

> Researcher: Now that we have seen all the STEM models out there, what is your model? What is your perspective on integrated STEM education?
>
> Tania: Personally, my subject is technology, so I will always integrate it with [the other subjects]. This is not one person's job. This is a collaborative job.
>
> Fatima: This is teamwork and if the team is strong, then it will be reflected in the work. We have to educate ourselves on how to share resources and to make them available to the students so they can learn by designing models. There should be some continuous training sessions so that we keep on learning effective ways to use STEM and bring it into our system.
>
> (Reflective Learning Conversation 4, 2016)

Team Purifiers reported that they were certain about the complex nature of the idea of integration of STEM. They personally experienced teamwork and saw how the act of teamwork contributed to merging their areas of expertise, and human and material resources for a common cause of the integration of STEM. Tania openly stated that STEM could not be a "one person's job." This and many similar exchanges occurred during the reflective learning team conversations. The team recognized the role that strong teamwork played in their successful completion of the oTPD-STEM program.

Collaborative reflections on the integration of STEM. The role of continuous reflection throughout the oTPD-STEM program played a vital role in Team Purifier's developing understanding of STEM integration. Various opportunities for reflective conversations either through the WhatsApp text chats, one-on-one interviews with the researcher, and reflective learning team conversations all provided the team with moments to pause and look back. They were then able to question their own views about their current and past teaching practices and reflect forward to their future teaching practices.

The team most frequently relied on reflecting back or reflection-on action (Schön, 1983) The excerpt below illustrates Fatima's deliberate move to reflect on the experiences she had had in the program, and later reflected forward to her future plans for implementing STEM.

> Researcher: As you have already experienced the integration of STEM through the practice unit and the STEM exemplar units… tell me how do you see integration of STEM now?
> Fatima: Actually… we did not seriously do the practice unit.
> Researcher: What makes you think that way?
> Fatima: Because at the time we did not have any idea about integration.
> Researcher: hmm…
> Fatima: That food unit was just like a practice trial… A starter.
> Researcher: Really?
> Fatima: So, to me this STEM exemplar unit, "Cool it" was way better then the first trial (practice unit). There are reasons for "Cool it" being better implemented, like maybe we devoted more time for implementation of the heat unit, and another thing was that we seriously focused our attention on it.
> Researcher: Right.
> Fatima: As you know, we are already used to integration of science and mathematics. But now we are doing it in much more detail. In our new academic session, we will make sure to include STEM integration right from the very start, highlighting the lessons that we have learned after implementing the STEM unit "Cool it." (Interview 3, Fatima, February 2016)

Model-enact-reflect cycle. Practicing within their team and collaboratively enacting the STEM exemplar units enabled Team Purifiers to understand that the integration of STEM was possible in their own school and within their classroom environments. Deliberate opportunities for reflecting back and reflecting forward (Killion and Todnem, 1991; York-Barr et al., 2006) allowed Team Purifiers to continually process their STEM experiences, connect them to their local context, and think about ways for adoption. After Fatima, Shaheen, and Tania collaboratively implemented the STEM exemplar unit "Cool it," they participated in a reflective learning team conversation. During the reflective conversation, the team talked about how the model-enact-reflect cycle helped them as a team to focus on exploring novel aspects of STEM.

> Researcher: Did you find any use of model-enact-reflect while exploring the STEM exemplar unit?
>
> Shaheen: The three of us have never worked so closely, but this unit has made us parse the unit, model it as a team, and then take the modeled parts of the unit into our classrooms. Finally, we shared our reflections with each other so we could make adjustments for the remaining parts of the STEM unit.
>
> Tania: This modeling part is very important for me. As I am a computer studies teacher, I find modeling very helpful. This gave me confidence to teach content other than my own expertise like teaching science or mathematics content for STEM.
>
> Fatima: This combo of model-enact-reflect is very useful for the kind of work we are doing as a team. Since integration of STEM has introduced us to some new approaches, sharing our thoughts and ideas helps us to understand it better.
>
> Researcher: Can you say more?
>
> Fatima: Evidence-based reasoning is a new thing. All of us modeled the claim, evidence, and explanation (CEE) task. This really helped us to move on and take it into our classrooms. Later we looked at students'

responses and decided to use it as a remedy for developing the reasoning skills of our grade 5 students.

Tania: This can also be helpful as a routine practice for us teachers to improve our teaching practices regardless of this oTPD-STEM program.

(Reflective Learning Team Conversation 1, February 2016)

The above conversation illustrates how Team Purifiers' reflected back and forward on a specific approach of the model-enact-reflect cycle while implementing the STEM exemplar unit. The team not only reflected back on this approach but also described how it benefited as a team and then reflected forward to other possibilities of using this approach even outside of the oTPD-STEM program.

Further evidence of Team Purifiers' reliance on reflection to develop their understanding of the integration of STEM comes from their reflective conversation over students' responses and social interactions during the enactment of the STEM exemplar unit. Team Purifiers discussed how a few students responded to teamwork during the storyboarding task.

Researcher: What is your biggest take-home message after using storyboarding in your classroom?

Fatima: Teamwork can be equally challenging for adults and students. We did the storyboarding task in teams. There were two out of six teams who totally failed as a team. We have been looking at this whole scenario.

Researcher: How did you handle this?

Shaheen: We all encountered similar situations. I found that reinforcing the rules (norms) of teamwork and then sticking to rules strictly [worked best].

Fatima: In my first classroom, students in non-functional teams were mostly disrespectful and did not follow their specific roles which led to unequal sharing of workload, and finally it was a disaster. But the next day I created shared expectations with the students…It helped!

Tania: We also divided the tasks among the team members for doing practical experiments for heat transfer.

Researcher: Did this help?

Fatima: Definitely! Our post-lesson discussion among our team [Team Purifiers] helped us handle this teamwork issue. I feel students saw us working as a team which was also an indirect effect to understand the value of teamwork. And then with more such tasks involving teamwork will help students get used to working as a team. (Reflective Learning Team Conversation 1, February 2016)

Fatima brought out the power of collaborative reflective practices (Desimone, 2009; Penuel et al. 2007) when implementing a new approach of integration of STEM as a team of three teachers who worked collaboratively to enact STEM integration in their classrooms. Fatima's struggled with her teams of students and how she and her team members could handle it through sharing their experiences and providing support for each other. Her reflections offer evidence to support the finding of the team's learning through constant reflection on integration of STEM. This was true whether it was students' responses, student interactions, or Team Purifiers' mutual interactions.

Integration of Scientific Practices before STEM

Team Purifiers' exploration of STEM integration in the oTPD-STEM program revealed the continual struggles of adopting a student-centered pedagogy. As with any living ecosystem, Team Purifiers functioned in CVE where multiple factors influenced the team's pedagogical decisions. While CVE emphasized thinking skills, inquiry skills, and creativity skills that constitute 21st century skills and are part STEM literacy, their written curriculum did not provide any evidence of developing these skills. Similarly, Team Purifiers continually struggled with the imbalance of content, pedagogy, and time. Team Purifiers knew the educational buzzwords such as scientific inquiry, project-based learning, and activity-based learning, but the data sources collected during the oTPD-STEM program did not reveal whether Fatima, Shaheen, and Tania had implemented these teaching approaches. All of these anomalies aside, Team Purifiers showed interest in understanding the practices of science and included some of the practices in their teaching following their experience during the implementation of the exemplar STEM unit.

Tension between teacher-centered and student-centered pedagogies. Team Purifiers struggled to choose a student-centered pedagogy over the traditional teacher-centered pedagogy. Fatima, Shaheen, and Tania frequently explored the subject of teaching pedagogies throughout the oTPD-STEM program. Shaheen expressed her own understanding of teaching pedagogies and her struggles with choosing between a teacher-centered and student-centered pedagogy during a reflective learning team conversation.

> Shaheen: Sorry to interrupt, we have this chapter on "States of matter." If we do it with hands-on [activities] it is very easy to teach and students also enjoy it, and most importantly remember it longer. If we do it in grade 5 with a hands-on approach, they will retain it till grade 7. But if we do it with the theory laden lecture method in grades 4 and 5, then we will definitely have to reteach it in grade 6 as well.
>
> Researcher: I see... you are suggesting a hands-on approach, aren't you?

Shaheen: My point remains the same…I understand the importance of teaching through hands-on, using materials, technology and what not …but the constraints of time, and inflexible and heavy loaded curriculum often push me towards rushing through the chapters and missing all the opportunities of involving students…you know how it drains our energy to manage all the resources, time, and availability of the computer lab for all sections.
(Reflective Learning Team Conversation 3, 2016)

Shaheen voiced her concern over this recurring problem in her teaching. She emphasized, “My point remains the same” when she restated her point about her helplessness to provide students with engaging learning opportunities over the high priority of completing the curriculum. Fatima and Shaheen both had witnessed and recognized the value of a student-centered pedagogy but continued to grapple with how to move towards these student-centered practices given their context. Team Purifiers also reflected on the significant change in the disciplined classroom layout to “purposeful chaos.” The team observed that losing the teacher-centered, highly disciplined classroom was the greatest challenge that they had to face. However, Shaheen commented in reflective learning conversation 2, “We are so used to disciplined classrooms that it took us some practice to allow purposeful chaos …We noticed our students are very collaborative which is very unlike our disciplined classroom.”

Team Purifier recognized the value of teamwork not for their own learning as teachers but favored teamwork for their students. However, while doing the storyboarding task, the team noticed that assessing teamwork was very challenging.

Shaheen and Fatima pointed out this particular area of teamwork in their WhatsApp text chat:

> Shaheen: How do you make sure that all students in a team are assessed fairly?
> Fatima: Yes, one team in my class was also complaining that two of them did the entire task and the other two barely did anything.
> Researcher: Did you assign each team member a different task?
> Shaheen: Students still get away with their roles easily.
> Fatima: I think next time let's make a rubric based on the tasks assigned.
> Researcher: An assessment rubric is a good idea. Also try making the team responsible for their individual tasks.
> (WhatsApp text chat, January 2016)

Team Purifiers challenged their own teaching pedagogies by trying out some student-centered approaches. In the above conversations, Shaheen and Fatima talked about the complexities of assessing teamwork. Unlike a teacher-centered pedagogy, student-centered approaches involve students in collaborative work where students are assessed on their individual efforts, but also on their contributions to teamwork. This aspect of teamwork raised questions about the already existing tension between teacher-centered or student-centered pedagogies.

In another example, Shaheen reflected forward on her plan to implement the engineering design challenge of designing a vaccine cooler. She shared that she would implement it as a semi-guided activity as she felt her teams of students might not be able to design the vaccine cooler on their own in the given time. Thus, she would guide students by helping them with some of the tasks (e.g., weighing the materials, sharing design ideas for the vaccine cooler) to help them move on with the design challenge. The excerpt below presents Shaheen's conversation with the researcher on planning the STEM exemplar unit.

> Researcher: How do you see yourself implementing the engineering design challenge of designing vaccine coolers?
>
> Shaheen: I have just skimmed through the challenge. It seems like a lot of work for teachers just for the preparation, and later when students start this challenge, there are so many steps involved. I think we will have to do work with the students.
>
> Researcher: I agree that you will need to arrange materials for the design challenge, and also in your team, you will need to work the challenge yourself first before doing it in the classroom. Can you say more on why would you need to work when students could try doing the design challenge in teams?
>
> Shaheen: Students will not be able to do it independently because it is their first time doing such kind of work. We [teachers] will do it with them for the first time. Later after experiencing it a few times they will be able to do it since they will be more independent. Like you told us about freezing the vaccine [ice cubes] and after 15 minutes its mass has to be calculated again, liquid removal and all that. Students will need our guidance for all those steps.
>
> Researcher: Yes, for the first time introduction to the design challenge, the teacher's guidance is very important. Later on, think about how you will train students to do such multilevel tasks on their own… like how they would be able to transition from one step to the other…
>
> Shaheen: Oh yes... When they have done it two or three times they would be able to carry out such tasks on their own.
>
> (Interview, Shaheen, 2015)

The excerpt above illustrates how Shaheen gradually took incremental steps toward a student-centered pedagogy. She recognized that the students had not been exposed to tasks like the engineering design challenge. Shaheen discussed how to guide students to move from one level of the engineering design process to the next so that they would stay on task. Shaheen also discussed how to provide guidance to students while testing their vaccine cooler prototype. She proposed preparing students for independent teamwork by exposing them to such experiences multiple times and eventually removing her scaffolds. Shaheen's conversation points to her intention to move towards a student-centered pedagogy after students gain two or three exposures to the creative, student-driven engineering design challenges.

At the end of the oTPD-STEM program, in reflective learning team conversation 4, the team acknowledged their gradual shift towards a student-centered pedagogy. Fatima, Shaheen, and Tania shared their reflections on their teaching methods and affirmed their efforts to become flexible and to shift from a strictly teacher-centered approach to a mix of teacher- and student-centered pedagogies. The following conversation, between the researcher and Team Purifiers is indicative of the extent to which Fatima, Shaheen, and Tania noticed changes in their teaching practices.

Researcher: Before I proceed ahead …how do you see your current method of teaching? How would you describe it?

Fatima: After a full years' experience of teaching science, I have observed that my teaching style has changed and is more focused towards experiential teaching. The change in me is also very visible. The class has become more interactive, and when students ask me for support I guide them to find out their solution using different resources that they can consult. I feel that now I am teaching differently, forcing myself to facilitate students' learning by not providing the answer but leading them to find the answer themselves.

Researcher: What would you say Shaheen?

Shaheen: Definitely… similar case with me! There are changes in my teaching. Previously, we were relying only on theory but now all the concepts we have taught are with practical and integrated activities using technology. And hands-on activities are being carried out for every topic that is performed in the school. Small models and practical applications are routine. They are very useful because they leave an impact on the minds of the students to help them in their exams too.

Researcher: Tania can you also shed some light on it?

Tania: Well…I am not teaching science, but what I see is that previously there was rote learning. Science was only taught by rote learning. Now it is integrated, practical activities are done and technology is involved.

(Reflective Learning Team Conversation 4)

This conversation confirms the team's reflections throughout the program. Fatima's statement, "I feel that now I am teaching differently, forcing myself to facilitate students' learning by not providing the answer but leading them to find the answer themselves" provides evidence of her past teaching practices and her present shift. Similarly, Shaheen's statement "Previously we were relying only on theory but now all the concepts we have taught are with practical and integrated activities using technology" is indicates that Shaheen started adopting some of the teaching pedagogies shared during the oTPD-STEM program. Finally, Tania who continued to see herself as a computer studies teacher, had previously used the phrase "rote learning" as a way of teaching science and acknowledged that the teachers in the program had started to collaborate and began using more hands-on approaches while teaching science.

Understanding practices of science. Team Purifiers was drawn towards trying to implement the practices of science (Bybee, 2011). Fatima, Shaheen, and Tania took special interest in five of the eight practices of science: (1) developing and using models, (2) planning and carrying out investigations, (3) engaging in argument from evidence (4) using mathematics and computational thinking, and (5) obtaining, evaluating, and communicating. As Bybee (2011) described, the practices of science have emerged based on "research on how students learn." Team Purifiers was inclined towards certain pedagogies involving teamwork and evidence-based reasoning that were practiced during the oTPD-STEM program after seeing the benefit to their students' learning. Team Purifiers first practiced the exemplar unit themselves as a team of teachers, followed by taking the STEM exemplar unit into their classrooms. Looking at the students' responses, Team Purifiers formulated their understanding and the need to use a particular task or pedagogy. In the same way, the practices of science also occurred. The students' responses to the use of some practices of science were extremely encouraging and motivated Fatima, Shaheen, and Tania to continue using those practices of science.

Team Purifiers found that the hands-on activities were valuable for student learning. They highlighted the students' involvement and learning as a result of these hands-on activities. While implementing the exemplar STEM unit, Team Purifiers found that simple scientific inquiry activities (e.g., to investigate heat transfer) were useful for their students. However, Shaheen's comment on the inquiry investigation task was very contradictory to what they were saying at other times. Shaheen said, "Inquiry for heat and heat transfer was interesting but was very lengthy… I felt if I could demonstrate some of those activities myself in class that would save on time and serve the purpose too." This comment indicates that Shaheen was routinely inclined towards teacher-centered practices. Despite their inherent tendency towards teacher-centered practices, Team Purifiers' interest in learning more hands-on and student-centered teaching pedagogies allowed them to explore STEM at a deeper level. Team Purifiers' move towards the practices of science was a beginning level of exposure to planning and carrying out investigations.

During their final reflective learning team conversation, Team Purifiers acknowledged the impact of hands-on activities on their teaching and on student learning. Involving students in exploration activities for different concepts allowed them to practice moving toward a student-centered pedagogy. During the reflective learning team conversations, Fatima commented, "I have observed that my teaching style has changed and is more focused towards experimental teaching" while Shaheen noticed, "Previously, we were relying only on theory, but now all the concepts we have taught are with practical activities and integrated technology." Tania also shared, "What I see is that previously there was rote learning. Science was only taught by rote learning…Now it is interactive and practical activities are done. Technology is involved." Fatima acknowledged that including small exploratory investigations and hands-on activities made her classroom interactive. Similarly, both Shaheen and Tania shared their change in teaching pedagogies from rote learning to more interactive and hands-on approaches. This suggests that Team Purifiers was not used to the student-centered pedagogies that are central to integrated STEM teaching.

Team Purifiers needed several cycles of rehearsal and implementation to become familiar with using student-centered pedagogies related to practices of science. For example, Team Purifiers expressed their comfort with using evidence-based reasoning after being exposed to it multiple times during the practice unit, and in the STEM exemplar unit. The following excerpt illustrates Team Purifiers' struggles with adopting student-centered pedagogies in reference to their experience with evidence-based reasoning tasks:

> Fatima: At first, I did not understand the claim, evidence, and explanation model, but now I feel this has shown me how to engage students to carry out small activities to create real data and make claims using that data.
>
> Tania: We are so used to rushing through the content to complete the syllabus that we hardly give time to students to get engaged in such inquiries.
>
> Shaheen: Honestly, we hardly get any time to think about how to improve our practice to let students learn better.
>
> Researcher: Can you say more?
>
> Shaheen: I want to think about new ways of teaching and examine how I teach…I am sure I need to come out of my routine teaching style. (Reflective Learning Team Conversation 3, April 2016)

Later, in the same reflective learning conversation, Team Purifiers shared their experience of using the claim, evidence, and explanation model in their classrooms in the excerpt below:

> Researcher: Now, in the scientific inquiry point, is there anything that you really liked or matched with your thinking? Please elaborate.
>
> Shaheen: Evidence-based reasoning... The students argue to prove their point of view using evidence from data. If we create such an environment of evidence-based arguments it could lead students to inquiry.
>
> Tania: Since students are curious, they freely ask each other and also are of the same age group (intellectually at the same level). I think it is easier to have an open discussion and exchange arguments with your peers … They don't do it much with their teachers.
>
> Researcher: Alright
>
> Shaheen: I was preparing my students recently for the Kangaroo Contest and I split them into two big teams and gave them different problems to discuss. I asked them to focus on the answers supported by evidence and the other team should keep their ears open for any missing evidence. So they had to defend their claim or counter the claim. This actually worked out very well…It was competitive and yet collaborative…Students learned from each other and students really enjoyed it.
>
> Researcher: That's great!
>
> Shaheen: To refute [the other students' claims], they had to do research as well. They had collected resources and had done a really good job of preparing for the contest.
> (Reflective Learning Team Conversation 3, 2016)

The above excerpt illustrates how Team Purifiers' was trying to implement evidence-based reasoning outside of the lessons provided in the oTPD STEM program by trying to improve their students' reasoning skills while preparing for a mathematics contest.

Team Purifiers used technology with a goal to strengthen sciencel however, they used videos and PowerPoint presentations in place of the traditional lecture method. Team Purifiers' intentions to use a student-centered pedagogy ended up being implemented in teacher-centered ways. To Fatima, Shaheen, and Tania, technology was the use of computer skills and the Internet. The excerpt below represents how Team Purifiers viewed and utilized technology:

> Researcher: How do you see the role of technology in the integration of STEM?
> Tania: The thing I have in my mind is that guiding students to first do investigations like we did in the STEM unit and then present their findings as proper presentations on PowerPoint.
> Shaheen: I asked students to research the best way to keep a vaccine safe and some students did a really good job. I asked them to use their research during exploration of the design for the vaccine cooler.
> Researcher: Fatima, can you please express your viewpoint?
> Fatima: Technology supports carrying out online research, provides resources, and allows us to present work.
> (Reflective Learning Team Conversation 2, March 2016)

The above evidence supports Team Purifiers' active engagement in understanding, learning and implementing practices of science within the oTPD-STEM program. However, they continued to implement practices of science in the most teacher-centered ways.

Factors Influencing Implementation of Integration of STEM

Team Purifiers participated in the oTPD-STEM program with an understanding that they would be able to try out new ideas in their classrooms. As with every living system, a number of factors simultaneously impeded and afforded their implementation of STEM. The description below presents the findings from Team Purifiers' interactions within CVE to illustrate the factors that influenced the team's implementation of STEM in a Pakistani context.

Curriculum as an impediment. The most prominent influence that Team Purifiers faced in the oTPD-STEM program was the very strong role of the prescribed curriculum at CVSS. Fatima, Shaheen, and Tania frequently referred to the fixed nature of the curriculum which gave them minimal opportunities to be flexible. The team felt helpless in making any adaptations in the existing curriculum as they were bound by both time and content. The following exchange between Shaheen and the researcher illustrates the existing tension due to the fixed curriculum. Shaheen found it difficult to cover the breadth of science content at the cost of depth of each content topic and commented, "More time is spent in co-curricular activities so in the end we have to squeeze in the academic time." In doing so, Shaheen often had to compromise on the depth of content and missed chances to make science relevant to students' local context.

> Researcher: I see…curriculum is not planned against the actual teaching time.
> Shaheen: Oh yes… We have to rush since we are a system that is running parallel to the CVE (Pioneer) School; exams are centralized, and we

also exchange papers with the CVE (Pioneer) School; they do ours we do theirs!

Researcher: This is only one aspect: there is a time-to-content conflict. How do you make changes if students' assessment show they need more in-depth knowledge for a particular content area?

Shaheen: This happens quite often. We arrange extra lessons to provide in-depth support for students if they lack it. We cannot change the order or pace of teaching. As I told you, our curriculum provides a detailed, compact plan for each term and we cannot omit or add anything for any reason as it barely allows us to rush through the curriculum, let alone make adaptations in it. All that counts is the number of topics covered and not the depth of each topic.

Researcher: You have mentioned that curriculum allows for more breadth than depth. Is the curriculum designed for the Pakistani context and does it connect with the local context of Lahore?

Shaheen: I do try to connect the science topics to the Pakistani context but in order to complete the plan, I get very little time.

(Shaheen-Researcher, Interview two, 2015)

Shaheen expressed her helplessness to bring more in-depth content and relevance to the classroom context, and particularly to alter any lessons that she, as a teacher, believed were significant for her students' learning. Shaheen also commented on one of the reasons for having a fixed curriculum as CVE and CVE (Pioneer) ran parallel within CVSS with a common assessment and examination system. Hence, none of the schools could deviate from the prescribed curriculum. Shaheen was already providing extra support for her students outside of the planned lessons as their curriculum did not provide time to reinforce or extend learning.

When implementing the STEM exemplar unit, Team Purifiers continually pointed out that if this unit were added to the curriculum, they would not have faced the challenge of arranging a separate time for integration of STEM in addition to their regular science lessons. Team Purifiers emphasized the need to initiate new approaches like STEM integration by involving the curriculum planners.

> Researcher: You said resources and time. How will you address these constraints?
> Tania: Most of the time resources are arranged and, somehow, time is also arranged. But the curriculum should be realistic with some flexibility. (Reflective Learning Team Conversation 2)

Fatima, Shaheen, and Tania continually shared their ongoing struggles with the wide breadth and narrow depth of the content knowledge they were teaching. The following exchange between Shaheen and the researcher reveals insights into this depth and breadth imbalance and how it played out in her teaching practices.

> Researcher: What I have understood from your point is that there is more content in your curriculum.
> Shaheen: Yes, no focus on depth. Like we did the “Earth and Space” [unit]… We did it in four periods [One class period is 45 minutes long]. You can well imagine that it has many topics: rotation, revolution, and change of seasons, Hubble telescope, orbit movement, moon and other multiple concepts. We did show them videos but on separate periods other than the science lessons.
> Researcher: Right! Did you show video clips to all sections?
> Shaheen: We don’t get much time to set up multimedia and videos and explain them side by side. This is not possible for all the concepts and all the classes to manage.
> (Interview, Shaheen, 2016)

The imbalance between the depth and breadth of content is quite evident. Shaheen shared ways she had attempted to overcome this challenge: by showing short video clips to start a concept, reinforce the concept, or wrap up the concept. However, still, the time-versus-content ratio was not practical for Team Purifiers in their classrooms. During another conversation, Tania also explained the same issue: "We are more focused on quantity. Like we do ten chapters in a rush rather focus on seven or eight chapters in great detail. Obviously when there is a lot of quantity, then quality suffers." Given the current situation, Team Purifiers was continuously rushing through the curriculum just to check off all the content, and were unable to pause and reflect on the learning needs of their students. The result was moving on without providing enough remediation or reinforcement of prior learning.

Principal-teacher cooperation. Team Purifiers admired their principal's support since the start of the oTPD-STEM program. The team acknowledged that their participation in the oTPD-STEM program was partly due to continual encouragement from their principal. Fatima shared in one of her WhatsApp text messages that she was very excited to attend a conference in Islamabad for two reasons: (1) it was her first experience to share her teaching practice with researchers and (2) her principal approved her leave for professional development and not as a leave of absence which is more common in such cases. During their first reflective learning team conversation, Team

Purifiers recognized the cooperative role of their principal. When asked how the principal helped in implementing the oTPD-STEM program, the following conversation transpired:

> Tania: Actually, the STEM exemplar unit was not part of the curriculum, so we decided to do it as an extra class, in that our principal helped us.
> Researcher: How did your principal help you?
> Tania: Our principal gave us an idea of taking 5 minutes from each lesson throughout the day and creating and extra lesson for doing the STEM unit in Grade 5. This was very helpful and three of us planned our timetable accordingly.
> Researcher: I really appreciate that you all worked very closely to carry out STEM in your classrooms.
> Shaheen: This credit also goes to our principal who encouraged us to do this project.
> (Reflective Learning Team Conversation 1, February 2016)

Team Purifiers acknowledged their principal's cooperation in being supportive of participating in the oTPD-STEM program, and also in creating time for implementing STEM in their classrooms. This cooperation was the first and foremost step that led to their exploration of a new teaching approach such as the integration of STEM in CVE.

Parent-teacher interactions. Team Purifiers also mentioned the important role of the parents from the beginning of this project. Shaheen shared her apprehension at the start of the oTPD-STEM program in a few of her initial WhatsApp text messages by sharing her concern about what the parents might think about the idea of STEM integration. In her WhatsApp text, Shaheen commented, "STEM looks interesting, but I do not know how parents will find it." Fatima shared similar thoughts by replying to Shaheen's text saying, "I know parents get upset if we do anything else besides preparing for assessments." At another point when the team was teaching the regular school curriculum along with the STEM unit during extra lessons, Shaheen, Fatima, and Tania talked about the parents' concern about doing two different concepts at the same time, but gaining their confidence helped to lessen this difficulty.

> Researcher: As you have completed most of your STEM units in your classroom, how do you feel about it?
> Shaheen: Basically, Tasneem, it is a good start. We are feeling confident about STEM and students are excited about the different kinds of activities. There is one problem. I have received notes from a few parents showing their concern about two different concepts taught each day. I totally agree with the parents because I am also noticing that for some children running two parallel concepts, is very confusing.
> Fatima: Exactly…I have also noticed the same. Doing two different concepts was creating some issues. Parents easily get worried if we teachers deviate from the planned syllabus.
> Researcher: I see…How did you satisfy parents?
> Fatima: Well,…we sent an information note to the parents describing the STEM project and listed the important features that you had shared in the beginning of this project.
> Tania: That was helpful but later during the PTA meeting, we displayed students' work to explain further for the parents. I wish we could have communicated to parents earlier.
> (Reflective Learning Team Conversation 1, 2016)

The team discussed the general response of parents including what satisfied parents and what things would upset them. Shaheen and Fatima both confirmed the parents' satisfaction when their children were being prepared for tests. In contrast, Tania shared that parents were easily upset if the daily routine of the school changed slightly. The team generally emphasized the need to have parents' involvement in the new teaching learning activities. The team also highlighted the supportive response of some parents who became interested in STEM. Once the team sent information about the STEM project, they also asked for the parents' cooperation and support in terms of giving their children guidance in gathering materials and resources to do the activities for the science content and the engineering design challenge. When the team began the STEM unit, some of the parents were very generous in contributing the necessary materials. The team felt relieved with this support because arranging all of the resources on their own would have been a significant challenge for them.

Researcher: Alright Shaheen, tell me more about the parents' involvement in creating an environment for STEM.

Shaheen: An environment should be created for learning… It is very important to note here: student learning should be open. Parents should be involved in it and teachers should also be involved in it. The students should not rely on facts alone; rather, they should validate it themselves. I asked students to test what happens when you mix warm and cold water. Many parents discouraged it by saying that their children might burn their hands, or their child already knew that hot water is more soluble. So… when we get these kinds of responses in which not everyone participates, then it becomes difficult for us to go on to the next stage. On the other hand, there were parents who had their children research about heat transfer, insulators, and conductors. These parents also sent the necessary materials for teaching these concepts.

Fatima: There is a mixed response from parents. I think if we could involve them [parents] in our teaching plans quite often, then they might understand the reality and willingly support our efforts.

Researcher: Tania, what do you think?

Tania: I am with Shaheen and Fatima. When parents team up with us, we feel so much relieved… Doing new and different activity becomes easy and also parents' support from home helps to reinforce our work. (Reflective Learning Team Conversation 3, 2016)

Team Purifiers was consistently in favor of involving parents in the teaching and learning of their children. The excerpt above illustrates how Team Purifiers felt supported or impeded by the parents' positive or negative attitudes or by their lack of involvement in their children's learning. Conclusively, parents' support did help Fatima, Shaheen, and Tania to implement the integration of STEM in their classrooms.

Answer to RQ 3: Ways to Explore Integration of STEM

The reflective practitioner partnership among Team Purifiers allowed Fatima, Shaheen, and Tania to explore the emerging idea of integration of STEM during their concurrent participation in the oTPD-STEM program and enactment of the integrated STEM curricular activities in their classrooms at CVE. Reflective practices with partners (York-Barr et al., 2006) on enactment of STEM units within a community of practice (Lave and Wagner, 1991) allowed Fatima, Shaheen, and Tania to view STEM within their own context. Team Purifiers explored the integration of STEM by reflecting back on the practice unit and the exemplar STEM unit and reflecting forward to envision their own mini-STEM unit and how STEM could look in CVE. Team Purifiers recognized the need to reflect on their practices as Shaheen commented, "Honestly we hardly get any time to think about how to improve our practice to let students learn better." Team

Purifiers was often engaged in reflecting back (Schön, 1983) but seldom found time to reflect forward (Killion and Todnem, 1991). As York-Barr et al. (2006) suggested, the reflecting back activity is the major input source for considering reflecting forward. Team Purifiers' exploration progressively moved towards learning more about identifying their personalized pressing needs such as making changes in their teaching pedagogies.

While exploring STEM integration, Team Purifiers' prominent teacher-centered pedagogies were revealed. Their inherent tendency to use teacher-centered pedagogies was evident in their reflections throughout oTPD-STEM. For example, Team Purifiers shared that they would do some of the inquiry investigations as teacher demonstrations. Similarly, when they implemented an engineering design challenge, they also shared their highly controlled teacher-centered approaches. It appears from the data on reflecting forward that Team Purifiers had a desire to move towards student-centered pedagogies and learn to integrate scientific practices which is a primary expectation for both reform-based disciplinary teaching of science and integrated STEM (Guzey et al, 2016).

Like any living system that interacts with its components to grow and develop, the school ecosystem of CVE where Team Purifiers enacted STEM integration is not excluded from influencing teacher practices and students' learning outcomes. A number of factors influenced Team Purifiers' exploration of STEM integration in CVE including the curriculum, principal, and parents. These factors contributed to building coherence and continuity to connect teachers and students with learning, but were restricted by personnel and available social resources within the school ecosystem (York-Barr, 2006). Team Purifiers' exploration of the integration of STEM was negatively impacted by the fixed curriculum at CVE, but the principal's and parents' cooperation facilitated Fatima, Shaheen, and Tania's evolution of the integration of STEM ideas.

Summary of the Case of Team Purifiers: a Visual Model

The case of Team Purifiers describes the complexities uncovered during the exploration of STEM integration within the oTPD-STEM program. Team Purifiers explored STEM within the school context of CVE. The case of Team Purifiers provides a focus on both the processes by which the participant teachers grappled with STEM integration, and the means by which their participant teachers' understanding was supported through their participation in the oTPD-STEM program.

A visual model (see Figure 4.7 was developed to illustrate the interplay of the six key themes presented in this chapter: (1) use of context, (2) centrality of science, (3) engineering seems distant, (4) reflective practitioner partnership, (5) integration of practices before STEM, and (6) factors influencing implementation of integration of STEM.

Figure 4.7 illustrates the visual model of the case of Team Purifiers with four main interactive components. The first component is the base of the model, depicting the CVE school ecosystem that combines the many "factors influencing implementation of integration of STEM." This represents the possible support structures of both human and material resources that can better facilitate teachers in their exploration of innovative ideas related to the integration of STEM from within the school. It also highlights some potential barriers along the way. The second component represents the teacher-student interaction that allowed Team Purifiers to enact the STEM integrated curricular activities of the oTPD-STEM program in CVE. As a result of this interaction, one of the key themes emerged as "integration of scientific practices before STEM.". Team Purifiers used model-enact-reflect as their pedagogy for understanding STEM integration. The model-enact-reflect pedagogy resulted in collaborative reflective practices among Team Purifiers and hence created the third component of this visual model, "reflective practitioner partnership" that was the key driver of Team Purifiers' understanding of STEM integration. The oTPD-STEM program engaged Team Purifiers in teacher-teacher and teacher-student interactions using model-enact-reflect pedagogy that resulted in Team Purifiers' "evolution in understanding STEM." This understanding allowed the teachers to shift from a SM/S.T.M. model to their own Stm----(e) model as the fourth component of this visual model and the key outcome of the oTPD-STEM program.

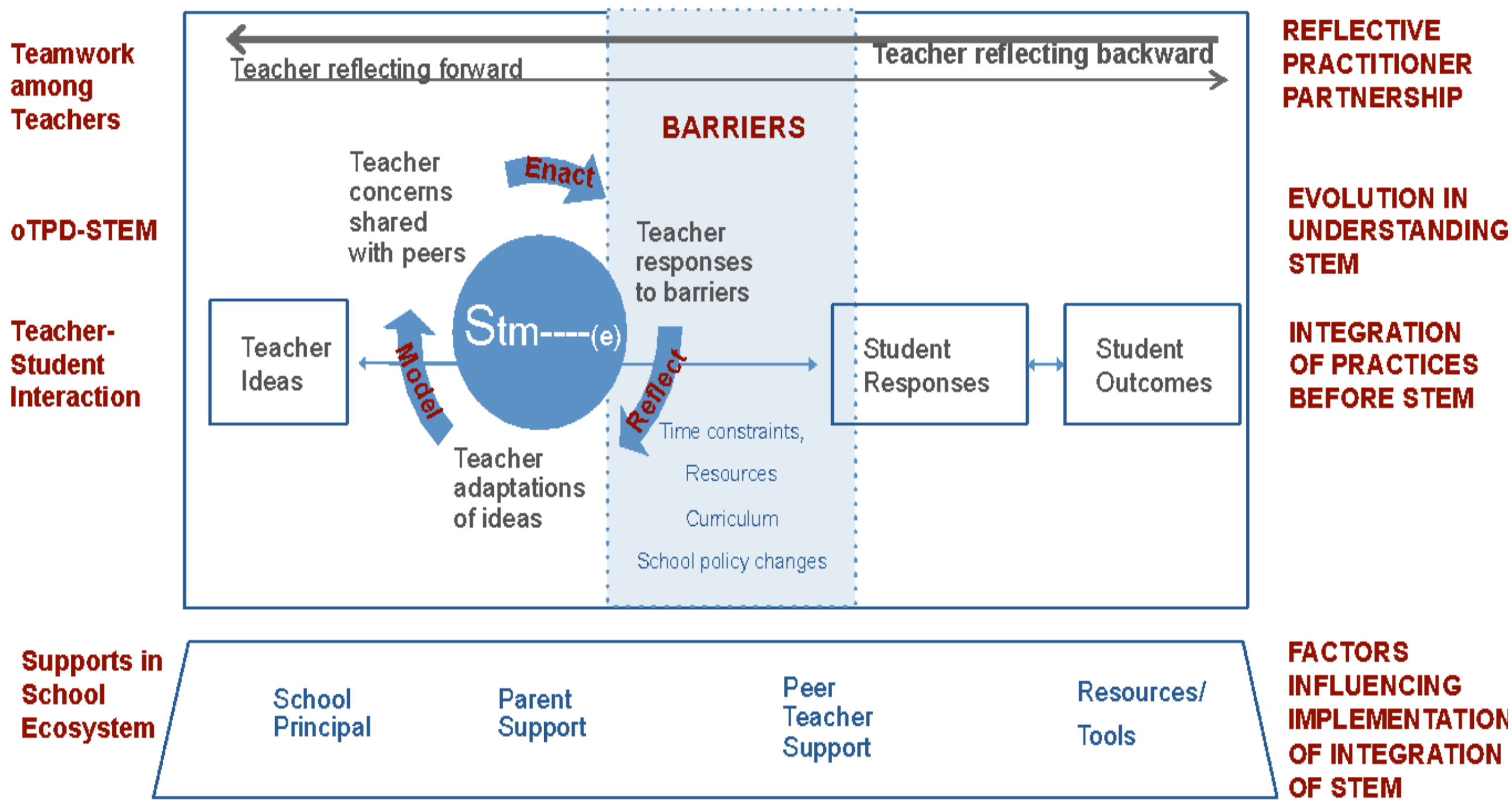


Figure 4.7. Visual model illustrating the case of Team Purifiers within the CVE school ecosystem.

To summarize, this visual model represents how Team Purifiers was engage an online teacher professional development program that allowed them to explore S integration using model-enact-reflect pedagogy within the constraints of the physica human resources in grade 5 at CVE. This model also presents the significant role of reflective practitioner partnership in exploring a multidisciplinary approach that led Purifiers to transform their understanding of STEM from a SM/S.T.M. model to a S -(e) model through their dual teacher-teacher and teacher-student interactions.

The final chapter presents a discussion on the combined findings of research question 1 shared earlier in chapter 3, along with the discussion on research questio and 3 presented in this chapter. Chapter V also shares implications of the research a recommendations for further research.

Chapter V- Conclusions

The oTPD-STEM program in this study used a three-phase design-based methodological framework derived from McKenney and Reeves (2012) and was grounded in the theoretical frameworks of reflective practices (Killion & Todnem 1991; Schön, 1983; York-Barr et, al, 2006) and community of practice (Lave & Wagner, 1991). Given the ecologically situated context of the oTPD-STEM program, the design-based research in this study allowed the researcher to develop a partnership with participant teachers in Lahore, Pakistan to collaboratively evolve the oTPD-STEM program through exploration, implementation, and evaluation. As a result of this partnership, the oTPD-STEM program evolved as an accessible online learning environment that provided the final eight participant teachers with opportunities to explore STEM integration by building a community of practice that integrated both asynchronous and synchronous technology-mediated environments. This study supports the use of McKenney and Reeves' (2012) DBR model as a structure that facilitates customization for being contextually responsive to participant teachers' needs. This chapter presents conclusions from the implementation of the oTPD-STEM program in two sections. The first section shares the discussion and implications of this study. The second and final section presents recommendations for future research and sustainability.

Discussion and Implications

Design-Based Decisions for oTPD-STEM

This dissertation study employed design-based research as a methodological framework (Brown, 1992; Collins, 1992; McKenney and Reeves, 2012) to detail the oTPD-STEM program for Pakistani participant teachers' needs. The following questions (research questions 1 and 3) provide guidance for important considerations in developing online TPD programs for teachers in developing nations, such as Pakistan:

> What instructional design components make an effective online professional development program to support teachers' understanding of STEM integration?
>
> How do teachers explore the idea of STEM integration through their participation in an online teacher professional development program?

This design-based oTPD-STEM program explored the potential of both online teacher professional development and the STEM integration approach for practitioners. Since only rare examples of design-based teacher professional development exist in international contexts, the following design principles articulated in this section are intended to serve as provisional guidelines to be refined over time through research and development:

- Explore options of accessible, free, and familiar social networking platforms and apps.

- Provide for both synchronous and asynchronous online interactions.
- Add face-to-face collaboration to build a community of practice (CoP).
- Design instructional tasks to balance theory and practice.
- Include opportunities to reflect and analyze practices.

Accessible, Free, and Familiar Social Networking Platforms and Apps. This study presents the significance of making use of social networking platforms and apps to facilitate teachers' professional development. The online professional development was welcomed by the Pakistani participant teachers, but the participant teachers' overstatement of their online competencies immediately became a barrier to their online interactions. The participants struggled to access and navigate the initial online learning management system (Moodle 2.8) and web 2.0 tools like Flipgrid, VoiceThread, and VideoAnt. Participant teachers' insightful suggestions informed major design decisions that contributed in the customization of oTPD-STEM 2.0. These major design decisions resulted in forming a Facebook group as a familiar, accessible, mobile device compatible LMS that provided opportunities to self-pace the responses. In addition, the inclusion of WhatsApp as the main learning and data-sharing platform added to the customization of oTPD-STEM 2.0. This finding adds to the existing literature that suggests using Facebook groups as a potential LMS for teaching and learning (Deng, Tavares, 2013; Grosseck, Bran & Tiru, 2011; Sanchez, Cortijo & Javed, 2014; Wang, Woo, Quek, Yang

& Liu, 2012) and proposes the potential use of WhatsApp in educational contexts as supported by Ahmed (2016) and Khan (2016).

The Pakistani participant teachers defined an accessible online environment as one that was mobile-friendly and was hosted on a familiar social networking platform that did not require them to log in or sign up each time they visited the platform. This finding is in accord with Burn (2011), who found that smart phones have outpaced the use of computers in Pakistan, thus making smart phones the most promising technology for distance learning teacher education in countries where use of smart phones is more popular than computers. Another study by Sari (2012) in Indonesia also reported that the use of social media on mobile phones was the most sustainable way to facilitate ongoing professional development of teachers. Mobile learning emerged as the most characteristic feature of this oTPD-STEM program. The participant teachers suggested the use of mobile learning when oTPD-STEM 1.0 was redesigned. This added feature of the oTPD-STEM program contributed in multiple ways. First, mobile learning increased access. Second, it allowed for more interactions among the participant teachers.

Synchronous and Asynchronous Online Interactions. Another important design principle was the availability of both asynchronous and synchronous communication tools. Similar to Susilo (2014), this study revealed that Facebook offers pedagogical, social, and technological affordances that allow for sharing of announcements, ideas, and resources. Unlike Susilo (2014), the teachers in this study did not use Facebook to engage in discussions but preferred WhatsApp for online interactions. WhatsApp offered the dual benefit of engaging learners synchronously along with the affordances for asynchronous communication that allows for the retrieval of posted messages, even if the user is offline or outside of network coverage. Facebook and WhatsApp together with the addition of Skype for group reflective meetings, afforded the participant teachers both asynchronous (anytime, anywhere) and synchronous (realtime) interactions using comfortable and familiar online tools.

Face-to-Face Collaboration to Build Community of Practice (CoP). Another critical insight from this study is the value of face-to face interactions within each team of oTPD-STEM participant teachers, in addition to the online interactions discussed above. The TPD literature (Desimone, 2009; Garet et al., 2001) highlights the significance of teachers from the same school building participating as a team, so they can discuss similar interests or teaching assignments. Collective participation, one of the core features of effective TPD used in this study (Desimone, 2009), when combined with face-to-face interactions within teams, contributed greatly towards generating comfortable online interactions of the participant teachers in the oTPD-STEM program. The pedagogy of practice: “model-enact-reflect” allowed the participant teachers to practice the STEM-integrated curricular activities within their teams and later to implement the same activities in their classrooms. The participant teachers used the opportunity both to plan for and reflect on their practice face-to face, and later online during reflective learning team conversations. This study supports the existing TPD literature (Desimone, 2009; Garet et al., 2001) and provides evidence of the added value of face-to-face interactions of the participant teachers who were in the same school building and teaching at the same grade level for developing online interactions in the oTPD-STEM program. Hence, oTPD-STEM emerged as a blended teacher professional development environment that drew upon face-to-face communities of practices within the schools, reinforced by innovative use of existing free, online environments used to support reflective practice and interaction.

Instructional Tasks to Balance Theory and Practice. The development of instructional tasks for oTPD-STEM required a balance between research and practice. This study offers pragmatic lessons on making instructional tasks grade-specific, relevant to the local context, and ready to implement without much adaptation. The participant teachers showed interest in STEM-integrated curricular activities that were grade appropriate and adapted to their local context. This study also offers solutions for engaging teachers with research on teacher practices. During oTPD-STEM 1.0, the participant teachers struggled with reading research articles. Connections to research were later facilitated by replacing the reading task with watching short video tutorials sharing the research findings on the practice of STEM integration followed by reflective learning team conversations. oTPD designers and developers should consider ways to include research driven ideas that can be readily transferred to teacher practices.

Opportunities to Reflect and Analyze Practices. The role of a reflective practitioner partnership within the oTPD-STEM program was the most critical design principle developed through this study. The oTPD-STEM program was designed to help participant teachers through continual reflective practices within a community of practice to address a problem of practice (exploration of STEM integration) using the pedagogy of practice (model-enact-reflect). In this study, the reflective practitioner partnership emerged as an effective pedagogy to learn about STEM integration. Since the participant teachers were engaged in exploration of integrating different disciplines for which all participant teachers did not have discipline specific expertise, collaborative reflective practices (York-Barr et al., 2006) and collaborative team teaching (Ritz & Fan, 2014) offered a potential way to explore STEM integration. Given the challenges involved in understanding STEM integration, collaborative reflections within the teams allowed the participant teachers to initiate conversations about STEM integration. This parallels the suggestions of the Royal Society (2007), "The impetus for meaningful STEM requires partnerships between teachers which thrive on dialogue, risk taking and a shared vision." Moreover, for successful implementation of STEM, the integrative approaches require close collaboration among STEM teachers and administrative support (Zubrowski, 2002). The reflective practitioner partnership that grew out of participating in the oTPD-STEM program adds to the existing research on the collaborative reflective practices (York-Barr et al., 2006) that was explored in an online environment for professional development with an added advantage of face-to-face collaboration among the participant teachers working in the same school building and teaching the same grade level. This research study also advanced the use of reflective practitioner partnerships to explore interdisciplinary approaches to content integration and shares the lessons learned with professional development designers and STEM teacher educators.

Evolution in Understanding STEM Integration

The design-based oTPD-STEM program allowed participant teachers to engage in STEM-integrated curricular activities that allowed the researcher to answer the question:

> How do Pakistani teachers' views of integration of STEM evolve throughout their participation in the oTPD-STEM program? **(research question 2)**

During the oTPD-STEM program, the participant teachers interacted with STEM-integrated curricular activities and in reflective conversations that facilitated the development of their understanding of STEM integration. The gradual evolution of Team Purifiers' views of STEM integration and their continual struggle to define the role and place of each discipline within STEM parallels the overarching struggle for understanding STEM integration in general (Bybee, 2013; Ritz & Fan, 2014; Williams, 2011). Similar struggles of understanding STEM integration and defining how each STEM discipline contributes to making connections is a widely accepted notion in the STEM literature. For example Honey, Pearson, and Schweingruber, (2014) have described this as, "Efforts to make connections among the STEM subjects are complicated by history of the K-12 curriculum and the 'place' of each of the disciplines within it" (p. 16). This quote illustrates the inherent complexity of STEM integration that was also experienced by the Pakistani participant teachers when they were exposed to the idea of integration of STEM while confronting the confounding constraints of their school curriculum.

The participants' STEM model illustrated four key characteristics: real world contexts, the centrality of science, the lack of importance of engineering, and the difficulty with student-centered pedagogies. A characteristic feature of Team Purifiers' model was the continual significance of context and real-world connections. This connects directly to the framework of Moore et al. (2014) which guided the development of oTPD-STEM. The first critical component of STEM according to Moore et al. (2014) is the purposeful and engaging context that weaves the science and/or mathematics content needed to apply the engineering design process in a partially or completely realistic situation. The participant teachers discussed the role of context as being vital for their STEM model. Guzey, Moore and Harwell (2016) also noted the prominent use of an engaging context for integration of disciplines to personalize students' learning in the literature.

The second prevalent feature of Team Purifiers' STEM model was the centrality of science. The Pakistani participant teachers saw science as a central discipline in STEM, mainly due to their emphasis on science learning of students and also based on how they wanted to view STEM in their own classrooms. The participant teachers had to adhere to their existing curriculum, which was science-focused rather than STEM-focused. This turned out to be a significant driver for participant teachers' decisions during the implementation of STEM-integrated activities. Williams (2011) acknowledged the existing school curriculum as one of the resistances against supporting teachers for a STEM-integrated approach. He called existing school curriculum "unchallengeable" and stated, "the rigidity and resilience of the school curriculum structures should not be underestimated when proposing reform" (p. 27). Similarly in this study, the influence of curriculum-driven teacher practices only minimally allowed the participant teachers to move out of their routine practices in spite of being exposed to opportunities for student-centered pedagogies in the oTPD-STEM program. This finding has strong implications for curriculum designers to include deliberate, pragmatic opportunities for student-centered pedagogies that could help teachers shift towards learner-centered approaches to teaching.

While Moore et al. (2014) also stressed the importance of science, it is stressed as providing the necessary knowledge for students to engage in engineering challenges. However, Team Purifiers found it difficult to visualize the role of engineering in STEM, which resulted in finally claiming engineering as a short extension activity that could allow students to apply and enhance their science and mathematics knowledge and skills. Concerns about engineering being left out of STEM instruction are very common both in the United States and in the international context (Johnson and Cotterman, 2013; White, 2014; Williams, 2011). The participant teachers grappled with understanding engineering primarily due to the non-existence of engineering in their current curriculum.

Finally, the participant teachers struggled with student-centered pedagogies that are central within the framework of Moore et al. (2014). The participant teachers recognized the usefulness of student centered-pedagogies but had an inherent tendency to drift back to teacher-centered pedagogies. Bybee (2014) highlighted the significance of using student-centered pedagogies and student-centered pedagogies and claimed that they are essential requirements for high quality STEM-integrated experiences for students (Moore & Smith, 2014). Unfortunately, Team Purifiers' reflective conversations revealed that in spite of acknowledging the significance of student-centered pedagogies, they inherently shifted to teacher-centered pedagogies especially while implementing integrated STEM. This finding suggests a need for a stronger focus on pedagogy in future oTPD STEM designs.

Overall, the implications of this dissertation study are threefold. This research advanced the use of DBR to develop an intervention for the context of Pakistan and also added to the relatively feeble research body of design-based dissertation studies. This study filled the gap in international research related to online teacher professional development in Pakistan, particularly by providing foundational understanding of potential of STEM in Pakistan. This study drew from international STEM literature

(English, 2015; Ritz & Fan: 2014; Williams, 2011) that is sparse in explaining STEM perceptions prevalent around the world. The STEM model of Stm-----(e) advances the understanding of STEM integration, especially in the context of Pakistan and, more generally, allows researchers to view how STEM integration is seen differently based on the curricular context and preference at the policy level. Finally, this research study advances the use of reflective practitioner partnerships to explore interdisciplinary approaches to content integration both in the local and global contexts.

Recommendations for Future Research and Sustainability

For more effective design based oTPD in the future, new studies are needed to share the complexities of design and research processes with young researchers, STEM educators, and online TPD designers. The researcher recommends the following concepts for future research and sustainability.

Online TPD Designers- Potential of School-Wide TPD

The design principles generated as a result of this DBR study would allow the online TPD designers to develop school-wide oTPD models in Pakistan. School-wide oTPD would offer the benefit of face-to-face collaboration along with online TPD to participant teachers who are interested in extending their professional skills to fit into their busy professional lives, while concurrently exploring and enacting innovative teaching approaches in the classroom. School-wide oTPD could provide sustained TPD for to teachers with the dual support of online and much needed face-to-face collaboration. The school-wide oTPD model enacted in this study in CVE would also provide an opportunity to sustain this graduate student initiative and extend the scope of this study by offering this model for wider use at CVSS (system wide). Perhaps this oTPD model could offer potential solutions for in-service teacher professional development in Lahore and for wider outreach to the rural parts around Lahore.

STEM Teacher Educators: Reflective Practitioner Partnerships for STEM Integration

Future research involving reflective practitioner partnerships, as a pedagogy of practice should begin to explore how to enhance the strength of collaborative reflections within a team, could allow STEM teacher educators to bridge the gap between theory and practice of STEM integration. This recommendation for future research has a wider scope of implementation as a reflective practitioner partnership has the potential to allow participants to benefit through collaborative reflective practices regardless of the context. This does not mean that reflective practitioner partnerships could develop without understanding and supporting participants to function within a specific the context, but reflective practitioner partnerships would create room for discourse in collaborative environments.

Practitioners: Support for Learner-Centered Practices

Future research is needed to involve practitioners in design-based oTPD to revisit their existing practices. Changing the inherent teaching practices of practitioners is a difficult issue but providing sustained oTPD for practitioners may begin a discourse on leaner-centered approaches. The value of discourse has already been documented in this study as reflective learning team conversations which offer a pedagogical structure for reflective practices. These practices are modeled by opportunities to enact and reflect on activities that use learner-centered approaches.

Conclusion

This design-based dissertation study has generated design-based principles for an oTPD-STEM program and elucidated ways to explore STEM integration in the specific context of Pakistan, but there are several more unanswered questions. Taking this study as a starting point, how can we move towards sustainable oTPD-STEM designs in the Pakistani context? What types of reflective practitioner partnerships could afford meaningful discourse among practitioners? What would participants' STEM perceptions look like after sustained oTPD-STEM? What types of challenges or opportunities are there when an oTPD-STEM model is used to support teachers for nationwide science education reform initiatives? Again, this exploratory study has offered a pragmatic starting point for online TPD designers, STEM teacher educators, and practitioners to continue STEM discourse within both local and international contexts.

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Appendix 3.1-Consent Form

(Consent Form in Urdu)

معلومات برائے تحقیق

آن لائن پروفیشنل ڈویلپمنٹ برائے سائنس ٹیکنالوجی انجینئرنگ اور ریاضی کے امتزاج کا پاکستان میں تعارف

آپ کو اس تحقیق میں شمولیت کی دعوت دی جاتی ہے۔ یہ تحقیق آن لائن آموزشی ماحول کا کھوج لگانے کے لئے ہے جو ان سروس سائنس،ریاضی کے اساتذہ کو سائنس ٹیکنالوجی انجینئرنگ اور ریاضی کے امتزاج کو پاکستان میں متعرف کروان میں مددگار ہو گا ۔ آپ کو اس تحقیق میں متوقع شمولیت کے لے منتخب کیا گیا ہے کیونکہ آپ جماعت چہارم سے جماعت ہشتم کو سائنس،ریاضی کے معلم معلمہ ہیں۔ اس تحقیق میں شمولیت کی رضامندی سے قبل آپ اس فارم کو بغور پڑھئے اور اس فارم میں موجود معلومات سے متعلق سوالات کے لئے مجھ سے رابطہ کیجئے۔

اس تحقیق کی محقق اعلی تسنیم انوار ہیں جو یونیورسٹی آف مینیسوٹہ کے شعبہ کریکیولم اینڈ انسٹرکشن میں پی ایچ ڈی کینڈیڈیٹ ہیں۔

طریقہ کار

اگر آپ اس آن لائن ٹیچر پروفیشنل ڈویلپمنٹ (او ٹی پی ڈی) جو کہ آٹھ ہفتوں پر مشتمل ہو گی، میں شامل ہونے کے لئے رضامند ہیں تو آپ کو درج ذیل کام کرنے ہونگے۔

انٹرویو(۱۵-۳۰ منٹ)
آن لائن سروے(۲ دفعہ)
ہفتہ وار ریفلیکشنز اور آن لائن اجتماعی مباحثہ
سبقی خاکے اور تکمیلی دستاویزات(۳-٤)

رازداری

اس تحقیق کا تمام ریکارڈ خصوصی پاس ورڈ والے محفوظ ڈیٹا بیس میں رکھا جا ے گا۔ اس تحقیق سے متعلق شائع ہونے والی رپورٹ میں ایسی کوئ معلومات شامل نہ ہونگی جن سے کسی بھی پارٹسپینٹ کی نشاندہی ہو سکے۔ اس ریکارڈ تک بحیثیت محقق اعلی میری رسائ ہو گی۔ اس تحقق کا کل دورانیہ ایک سال ہو گا، جس کے بعد تحقیق کا تمام ریکارڈ تلف کر دیا جاے گا۔

ارادی شمولیت

اس تحقیق میں شامل ہونا آپ کی اپنی مرضی پر منحصر ہو گا۔ آپ کا فیصلہ آپ کے یونیورسٹی آف مینیسوٹہ، ٹوئن سیٹیز کیمپس کے ساتھ موجودہ یا مستقبل میں قائم ہونے والے تعلقات پر اثرانداز نہ ہو گا۔ اگر آپ اس تحقیق میں شامل ہونے کا فیصلہ کرتے ہیں تو آپ کو پورا اختیار ہو گا کہ آپ کسی سوال کا جواب نہ دیں یا تحقیق سے کسی وقت علیحدہ ہو جائیں۔

رابطہ برائے مزید معلومات

۳۲۰ لرنیگ اینڈانوائرمیٹل سائنسز بلڈینگ
۱۹٥٤ بیوفورڈ ایوینیؤ
سینٹ پؤل، ایم این
دفتر کا نمبر ٦١٢٦٢٦٣٦٤٢

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ڈاکٹر بھاسکر اوپادھے(ایڈوائزر):bhaskar@umn.edu، فون نمبر:٦١٢٦٢٥٣٢٨٦
ڈاکٹر جیلئن روہریگ(کو ایڈوائزر)roehr013@umn.edu، فون نمبر: ٦١٢٦٢٥٠٥٦١

مزید معلومات کے لئے درج ذیل پتہ پر رابطہ کیجیے:
ریسرچ سبجیکٹز'ایڈوکیٹ لائن،
ڈی ٥٢٨ مئیو،
٤٢٠ ڈیلاوئر سٹریٹ، ساؤتھ ایسٹ،
مینی ایپولیس،مینیسوٹہ ٥٥٤٥٥
فون نمبر: ٦١٢٦٢٥١٦٥٠

(اس فارم کی کاپی آپ کو اپنےریکارڈ کے لئے دی جائے گی۔)۔

(Consent Form in English)

INFORMATION SHEET FOR RESEARCH

Online Teacher Professional Development to introduce to introduce integration of STEM in Pakistan

You are invited to be in a research study of "Online Teacher Professional Development (oTPD) to Introduce Integration of STEM in Pakistan". The present study aims to explore an online learning environment that could introduce and support in-service science/ mathematics teachers in integration of Science, Technology, Engineering and Mathematics. You are selected as a possible participant because you are a science /mathematics teacher at grade 4-8 level. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by: Tasneem Anwar, PhD candidate in the Department of Curriculum & Instruction at the University of Minnesota.

Procedures:

If you agree to be in this study, we would ask you to do the following things:

1. Interview (15-30 minutes)
2. Online survey (twice)
3. Weekly reflections & Online group discussions (weekly for 8 weeks)
4. Lesson Plans & Implementation documents (3-4 depending upon the number of lessons in mini STEM unit).

Confidentiality:

The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify a subject. Research records will be stored securely and only researcher will have access to the records. The record of oTPD data will be accessed by the principal investigator only and it will be erased from the password protected, secure data base after the research completes after a year from its start.

Voluntary Nature of the Study:

Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota, Twin Cities Campus. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions:

The researcher conducting this study is: Tasneem Anwar, Dr. Bhaskar Upadhyay, and Dr. Gillian Roehrig (advisors). You may ask any questions you have questions later, you are encouraged to contact them at:

320 Learning & Environmental Sciences Bldg.
1954 Buford Avenue
Saint Paul, MN 55108
Office Phone: 612-626-3642
Tasneem Anwar (PhD candidate and researcher): anwar013@umn.edu
Dr. Bhaskar Upadhyay (Advisor) : bhaskar@umn.edu, (612) 625-3286

Dr. Gillian Roehrig (Co Advisor) : roehr013@umn.edu, (612) 625-0561

If you have any questions or concerns regarding this study and would like to talk other than the researcher, you are encouraged to contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. Southeast, Minneapolis, Minnesota 55455; (612)625-1650.

You will be given a copy of this information to keep for your records.

Appendix 3.2-Interview 1 (Face-to-Face)

1. Please define these disciplines:
   Science
   Technology
   Engineering
   Mathematics
2. Can you explain the term "Integration" for me?
3. What do you understand from integration of science, technology, engineering and mathematics?
4. How often have you used integration while teaching science or mathematics?
5. Describe an integrated lesson that you have taught.
6. What are the strengths and weaknesses of using integration of science, technology, engineering and mathematics in your teaching?
7. Do you believe the integration of science, technology, engineering and mathematics is purposeful or could help your students learn science?
   If yes, how?
   If no, why not?

Appendix 3.3-Pre-Survey

Name *
Write your full name.

Educational Qualification *
What was the highest level of Education that you have completed?

Professional Degree/Certificate in Teaching *
Have you got a professional degree/certificate in teaching? (Mention all like: B.Ed/M.Ed/M.Phil/PhD)

Professional Development (PD) *
Have you participated in professional development activities or programs? Make a chronological list indicating the title of PD, conducted by, and the duration of PD

Teaching Experience *
What is your teaching experience? (Name of Institution, Teaching Position, Grade level you taught at, Number of years)

Name of Institution/School *
Where are you teaching currently?

Current Teaching Position *
In what subject areas and grade levels are you teaching at present?

Students' Background *
Who are the students in your school? (Neighborhood residents, Army background, Civilian background etc)

Weekly Teaching Activities *
In a typical week, how many hours do you spend at school teaching mathematics/science/computer studies?

In a typical week, how many hours do you spend at school teaching other subjects?

In a typical week, how many hours do you spend at school meeting with other teachers to work on curriculum and planning issues?

Preference of Language for Communication *
What language would you prefer to post/share your responses during this oTPD (You can check more than one box)

- Urdu
- English
- Roman Urdu
- No preference

Teamwork *
How would you prefer to work in teams?

- random teams
- same school teams

Mode of Communication with Instructor *
How would you like to communicate with your instructor (You can check more than one option) ?

- via moodle (your oTPD platform)
- via email
- via whatsapp

Norms for Participation *
Please suggest atleast two norms (Netiquetts) for our interaction in this online environment.

Expectations *
What are your expectations from this oTPD?

Availability for Google Hangout Sessions
What is the most suitable times for Google Hangout session #1? (Time mentioned in Pakistan Standard Time-PKT)

What is the most suitable times for Google Hangout session #2? (Time mentioned in Pakistan Standard Time-PKT)

What is the most suitable times for Google Hangout session #3? (Time mentioned in Pakistan Standard Time-PKT)

Appendix 3.4-Learning Activities of Module 1

Purpose

To reflect at our own teaching practices and explore effective teaching pedagogies. Where are you now? Moving towards Integration of Science, Technology, Engineering & Mathematics (STEM)

Learning Outcomes

Upon completion of this module, you will be able to:

- Identify best teaching practices
- Visualize integration of STEM

Learning Resources

Required Resources

- "Advancing STEM Education: A vision 2020" Bybee, 2010

Learning Activities

Follow the given order to go through each of the learning activities:

- Reading: "Advancing STEM Education: A vision 2020" Bybee, 2010
- VideoAnt 1: View any three videos (first 20 minutes of each video) and annotate the teaching practices that you notice. (Small teams)
- Forum 1: Each participant will respond to a posted question/topic by replying to instructor at least once and peers twice. (Whole group discussion)
- VoiceThread 1: After listening to VoiceThread, visualize integration of STEM in your classroom and share your ideas by recording your comment about "what can be learnt from research in integration of STEM and which teaching practices do we need to work on in order to be proficient in STEM pedagogies?" (Whole group discussion)
- Flipgrid 1: Reflect at your own teaching practices- what all you already do? What is needed? How can you use integration of STEM in your classroom? (any concerns/fears and how to overcome those?). Each participant will respond to the question posted on the Flipgrid.
- Classroom Activity 1: Ask your students to brainstorm interesting problems around them (in their neighborhood/city)

Appendix 3.5 Practice Unit

Unit – Food Our Source of Energy

Motivating and Engaging Context:

Obesity and overweight is increasing worldwide. Pakistan is not beyond impact. In this situation, The Children Hospital and the Institute of Child Health, Lahore has invited students from different age groups to join hands in their effort to raise awareness among children and youth to develop healthy eating habits and healthy life style. Students will use the data to propose the best way to spread this awareness among the community.

Inclusion of Science and Math Content:

Science: Food groups; Energy value of food; Balanced diet.
Math: Number sense; Read data in a graph and analyze it.

Engineering Design Challenge:

Looking at the data from http://vizhub.healthdata.org/obesity/ students will:

1. define the problem.
2. explore what others are doing to address the problem.
3. design atleast three options to address the problem. (Looking at the positive and negative impacts of each option, select one best option).
4. create the solution using the best design option, considering constraints (cost, time and health gains).
5. try out the solution by sharing out "solution" supported by evidence from data and being reasonably within the constraints of cost, time and health gains.
6. Redesign-make solution better after sharing ideas with other groups and looking at the feedback received.

Student Centered Pedagogies:

Claim, evidence and explanation would be used; and collaborative work would carry out in groups of 3-5 children per group.

Learning from failure:

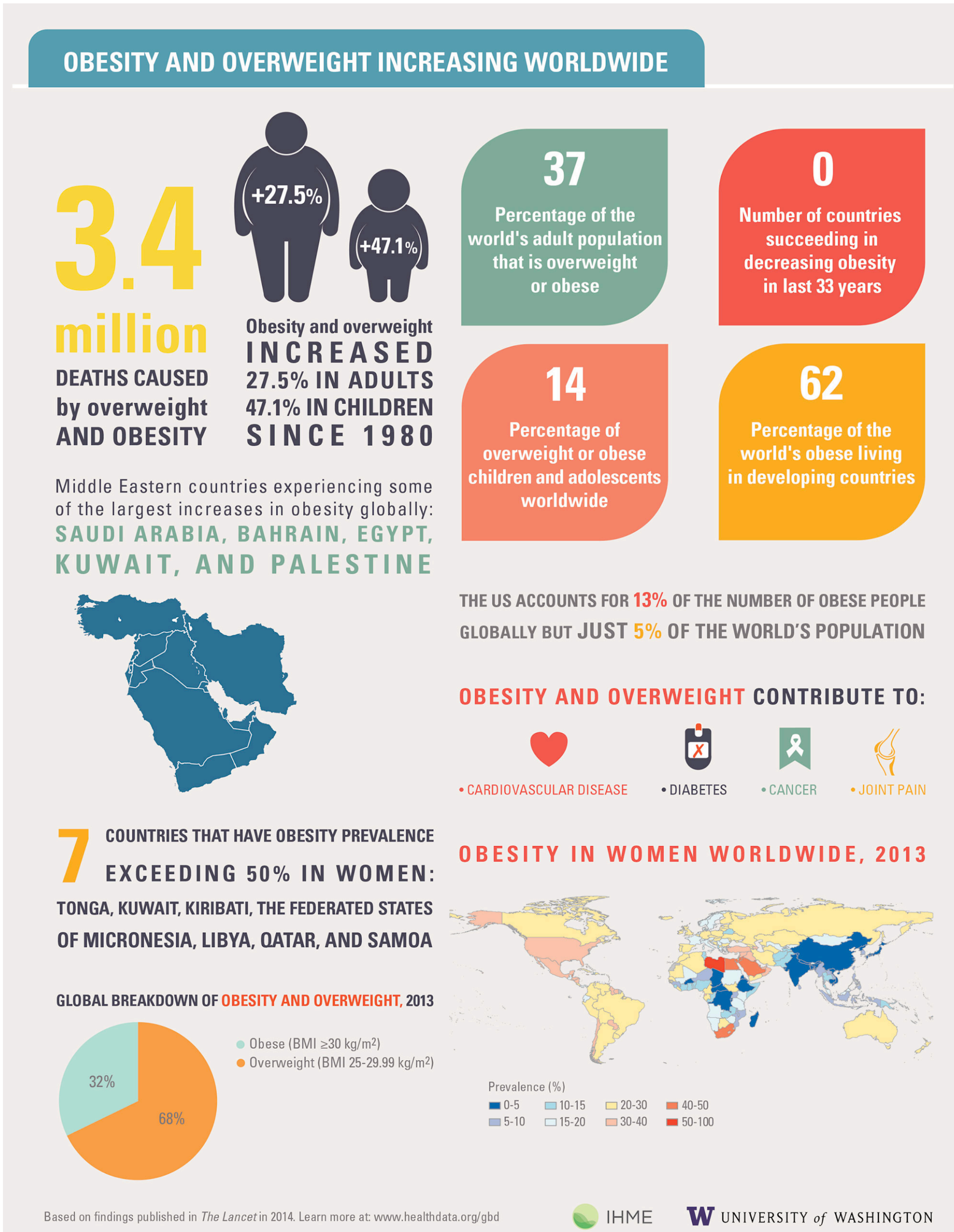
Make it better or redesign will facilitate students to reflect back on their design and help them to assimilate their learning.

Teamwork and Communication:

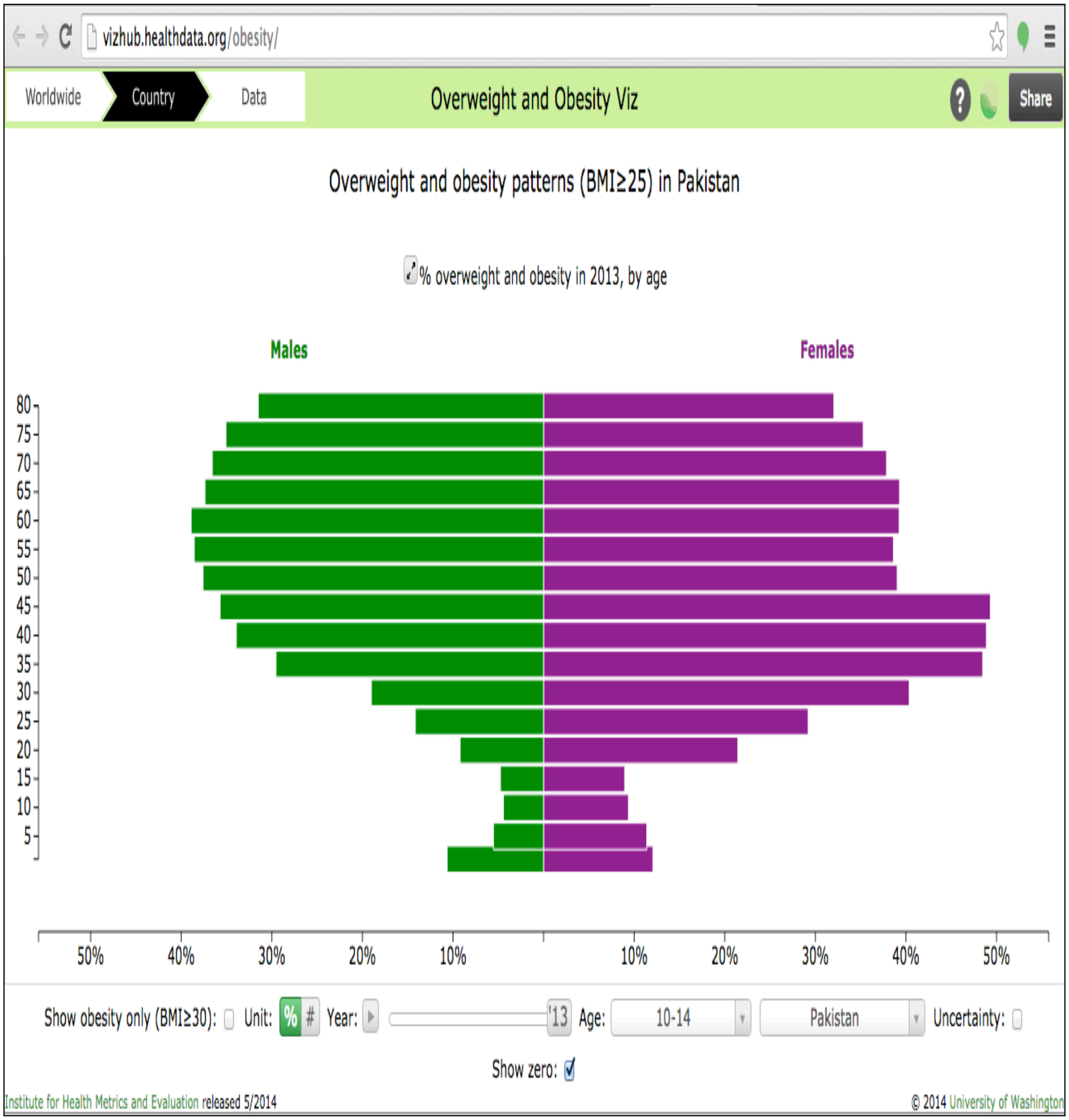
Groups will question each other about the data and what do they see as a trend. Later on, each team will collaboratively explore; design and share ideas to be able to communicate their proposal to the Children Hospital and the Institute of Child Health, Lahore**.**

Introduction to the Context

Data on Obesity Worldwide



Data on Obesity in Pakistan



Look at the above data and answer the following to understand the problem: Make a claim using evidence from the data.

1. **What health issues does obesity and overweight lead to?**
   Claim:____
   Evidence:______________________________________
   Explanation:____________________________________

2. **Why obesity and overweight is an issue worldwide?**
   Claim:____
   Evidence:______________________________________
   Explanation:____________________________________

3. **What is the global trend of increase in obesity and overweight?**
   Claim:____
   Evidence:______________________________________
   Explanation:____________________________________

4. **What is the trend of increase in obesity and overweight in Pakistan?**
   - **Between males and females**

   Claim:____
   Evidence:______________________________________
   Explanation:____________________________________

   - **Between boys and girls**

   Claim:____
   Evidence:______________________________________
   Explanation:____________________________________

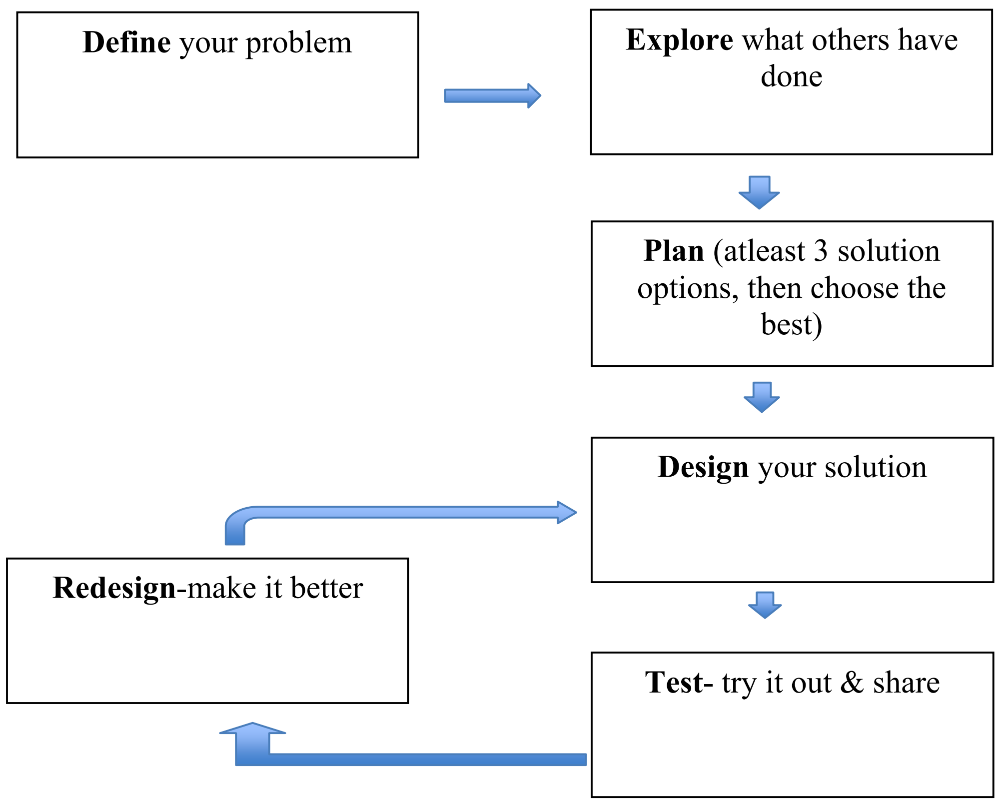
5. **How is the trend of increase in obesity and overweight in Pakistan is similar/different than the trend worldwide?**
   Claim:____
   Evidence:______________________________________
   Explanation:____________________________________

6. **After answering all the above questions, define the problem.**
   Claim:____
   Evidence:______________________________________
   Explanation:____________________________________

The Engineering Design Challenge

Challenge: The Children Hospital and the Institute of Child Health, Lahore has invited students from different age groups to join hands in their effort to raise awareness among children and youth to develop healthy eating habits and healthy life style. You will use your claims supported by evidence from the data to propose the best way to spread this awareness among the community.
Constraints: Your proposed solution must:

- be cost effective
- be time efficient
- offer visible health gains



Lesson Plan

Plan	Comments
Introduction: 1. Review the five food groups (vegetables, fruit, grains, protein, and dairy) and ask: a. Who can name a food group? b. Who can name a food in that food group? c. Who can name two more foods in that food group? d. Who can name their favorite food in that food group? e. How does that food group keep you healthy? f. Why is that important for students your age? 2. Students should understand they need foods from ALL five food groups because each food group helps them stay healthy in a different way. Ask: a. Why do you think you need to eat foods from each of the Five Food Groups every day? (Accept all reasonable answers) b. What do you think would happen if a person only ate from four of the food groups? (His or her body would be missing something to stay healthy) c. What if a person only ate foods from three food groups or two food groups? (His or her body would not get everything it needed to stay healthy) **Icebreaker** –"We Need All Five!" 1. Ask them to listen carefully and follow your directions: ● Look at one of your hands. What do your hand and the Five Food Groups have in common? The hand has five fingers and there are Five Food Groups ● Have students take out a pencil or pen and paper and: 1.Write your first name on the paper 2. Now, pretend you don't have a thumb. Write your last name using just the four other fingers to hold the pencil. 3. Now, pretend you don't have your pointer finger. Using your thumb and other three fingers, write your telephone number. 4. Now, pretend you don't have a middle finger. Use your thumb, your pointer finger, and your other two fingers, write our room number. ● How easy is it to write when you're missing one of your five fingers? ● How easy would it be to stay healthy if you didn't eat one of the Five Food Groups? ● Reinforce that students need all Five Food Groups every day: Each food group helps the body stay healthy in a different way. So to grow and stay healthy, you need to eat from every food	Engage students in discussion on healthy eating habits.

group every day.	
Engineering Design Challenge: 1. Ask students to read the data on "Obesity Worldwide" and "Obesity in Pakistan". 2. Introduce students to claim- evidence and explanation and ask them to respond to the questions related to data using the claim and evidence. 3. Discuss what did they see in the given data and ask questions to help them identify the problem. 4. Introduce them to the challenge "Help The Children Hospital and the Institute of Child Health, Lahore to spread awareness about Obesity and propose ways to reduce the problem". 5. Talk about the constraints (limitations) involved and highlight the role of these constraints in our decisions for solving real-world problems as engineers. 6. Introduce the engineering design process to students (Identify, explore, plan, design, test, and redesign). Talk about the role of redesign in solving real-world problems. 7. Ask groups to "Explore" four stations (display information on each corner of the classroom and mark each corner as a station) to explore the resources about the problem. Remind them to take notes when they explore each station. 8. Brainstorm ideas from each group by asking: ● What makes obesity a problem? ● What could we do to address the problem? ● What are some of the different ways to change people's thinking? 9. Give students specific time to reach the "Test" phase. Ask each group to share their design along with how they have addressed the constraints. Ask each group to take notes of their personal thoughts about their design and what feedback other groups have offered. 10. Ask groups to go back and "Redesign" on the basis of the feedback/observations during the "Test" phase.	Students will work in groups of 3-5 students each. Claim- a statement that answers a question. Evidence: The data that supports a claim. Explanation: How and why evidence supports a claim using science ideas. Four stations: Resource for Station 1,2, 3 and 4 is included along this lesson plan Brainstorm: Encourage students to put their ideas on the table and stress that each idea is valuable- each member of the group must listen to and respect others' idea.
Closure: Gallery walk: Each group will share their final design. Facilitate students to communicate their solution to the problem posed.	Gallery walk: Each group will walk around to see others work
Assessment: Each group would be assessed on their engineering design and to what extent they design within the given constraints.	

Appendix 3.6 Exemplar STEM Unit

STEM Curriculum Unit- Cool It!
Class - 4 and 7
Time Duration-5 lessons

Unit Summary:
Students review the concepts of heat and heat transfer and follow the engineering design process as they explore the problem of keeping the vaccines cool. Students will plan, design, and test a "model vaccine cooler" that will keep the malaria vaccine from melting too quickly. After the initial design, students will evaluate their models and use the information generated during group share out to redesign and improve their vaccine coolers.

Motivating and Engaging Context:
Almost everyone has experienced vaccinations, but why do we get them? In Pakistan alone, 177 million of the 180 million population is at risk of malaria with 3.5 million confirmed cases of malaria each year most of them being young Pakistani children. With the most recent breakthrough in the worldwide efforts to fight against malaria, the European Medicines Agency (EMA) has approved the first malaria vaccine- also the first ever vaccine to provide protection from a parasite. Now, the biggest challenge is to store these vaccines at the correct temperature. Directorate of Malaria Control (DMC) at Islamabad has invited the schools to join hands in solving the challenge of storing and transporting the precious malaria vaccines at the correct temperature for 10+ days, even when the power is unreliable.

Science Connections	Technology Connections	Engineering Connections	Mathematics Connections
• Temperature and Heat • Conductors • Insulators	• Measure temperature and weight • Multimedia for projecting Dailymotion video clips	• Identify/investigate design solutions • Working within constraints • Test/redesign • Communicate results	• Surface Area • Number sense • Read data in a graph and analyze it.

Unit Breakup

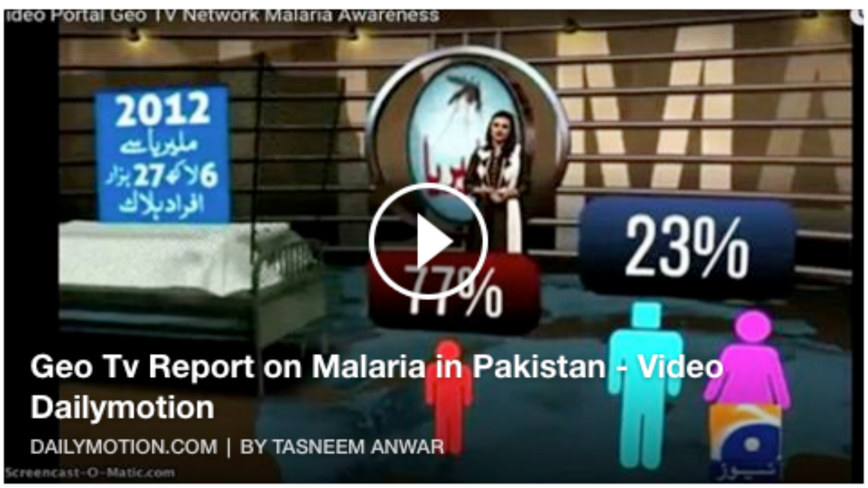
Integration of STEM	Lesson 1	Lesson 2	Lesson 3	Lesson 4 &5
	Vaccination/Setting the Vaccine	Heat Transfer/Surface	Conductors & Insulators	Engineering Design

	Cooler Challenge	Area		Challenge

Lesson 1– Vaccination (Setting the Vaccine Cooler Design Problem)

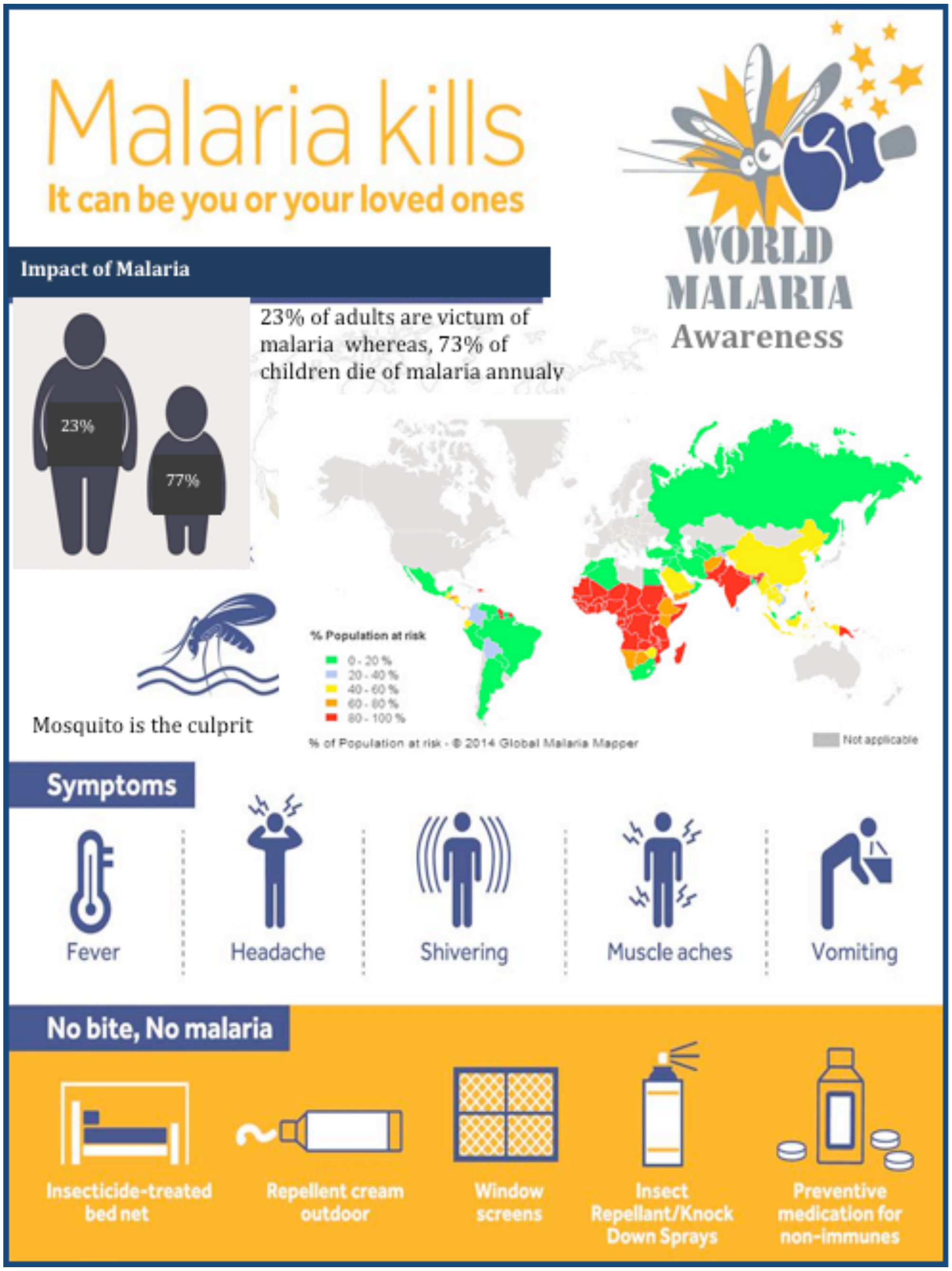
Task 1: Watch "Malaria Awareness" Video. After watching video clip, looking at the data presented, each participant teacher will make 'a claim', supported by 'evidence' and then write 'explanation' for the claim made.

Claim:____
Evidence:____
Explanation:____



Task 2: Watch video clip on "How Vaccines Work?" After watching the video clip make a 'Storyboard' to represent atleast 3 main ideas presented. Do this task as a team. Each team has to submit one storyboard on "How Vaccines Work?"

Task 3. Look at the data below and answer the following to understand the problem: Make a claim using evidence from the data. (Question 1 is done as a sample)



1. **Why should Pakistan care about malaria?**

Claim: . Malaria is a major health threat for Pakistan.

Evidence: 80-100% of Pakistani population is at risk of getting malaria.
Explanation: Mosquito spreads malaria and if preventive measures are not taken, malaria can become uncontrollable. According to 2014 Global malaria mapper, 80-100% population in Pakistan is at risk of malaria that makes it a major health threat.

2. **Who is most likely to get sick with malaria; adults or children?**
   Claim:____
   Evidence:____
   Explanation:____

3. **What preventive measure do you consider most effective to control malaria?**
   Claim:____
   Evidence:____
   Explanation:____

4. **Which continent is at the maximum risk of malaria?**
   Claim:____
   Evidence:____
   Explanation:____

5. **How can we lower down the risk of malaria?**
   Claim:____
   Evidence:____
   Explanation:____

Lesson 2 & 3 – "Heat and Heat Transfer"& "Conductors and Insulators"

In these two lessons students will carry out scientific inquiry to understand "Heat and Heat Transfer"& "Conductors and Insulators". Students will inquire the following problems and share their findings as a storyboard:

Problem 1

- You want to bring a juice can on a field trip and drink it for lunch, but you want it to still be cold when you drink it and you don't know what the best thing would be to keep it cold.
- Which would work best?
  - Aluminum Foil
  - Cotton Sock
  - Paper Towel
  - Plastic Wrap

Wool Sock
Nothing

Instructions

- You will need six cold juice cans (any kind) and a thermometer
- Remove all six cans from the refrigerator and wrap each can as quickly as possible, handling the can as little as possible. Cover the can entirely including the top and bottom
  - Can 1: plastic wrap (three times around the can)
  - Can 2: wool sock (needs to be natural wool)
  - Can 3: paper towel (three times around the can)
  - Can 4: aluminum foil (three times around the can)
  - Can 5: "naked"
  - Can 6: cotton sock
- After 3 hours open each can and take the temperature of the can (be careful that the thermometer is not touching the sides or bottom of the can)
- Record your data

Sharing Findings of Problem 1

- Panel 1: Explain why the can of juice heats up after you take it out of the refrigerator. Use words and pictures.
- Panel 2: Which material will work the best to keep your juice can? Explain your answer using words and pictures
- Panel 3: Which materials worked the best? Explain why this material works the best to keep the can cold. Include vocabulary words: heat transfer, temperature and insulator. Make sure you show the direction of heat transfer in your panel.

Problem 2

- You want to choose a spoon that will work best to keep an ice cube cold.
- Which would work best?
  - a plastic spoon,
  - a metal spoon

Instructions

- You will need a plastic spoon, a metal spoon and two ice cubes.
- You will place an ice cube on each spoon, hold the spoons and make observations of the ice cubes.
- Record your data

Sharing Findings of Problem 2

- Panel 4: Predict which spoon will work best to keep an ice cube cold and explain your prediction
- Panel 5: Which spoon kept the ice cube cold longer? Explain your observations using pictures and words. Include vocabulary words: heat transfer and conduction. Make sure you show the direction of heat transfer in your panel.

- This is an example of conduction- heat transfer through direct contact. Conduction is explained:
  http://dai.ly/x3fkhrb

Problem 3

- You want to see how hot and cold water transfer heat energy when they mix together.

Instructions

- You will need a large container (large Pyrex casserole dish or plastic storage tub) of room temperature water, a colored ice cube (prepared ahead of time by adding a little food dye into my ice cube tray – I use blue in my class to represent cold), and a small glass bottle with a different color of food dye (I used red in my class to represent hot) and hot water.
- Place the ice cube and glass bottle into the tub of water and let go. Sit back and observe convection in action. If you are having trouble, take a look at the video link below:
  http://dai.ly/x3fki1x

Sharing Findings of Problem 3

- Panel 6: Predict what will happen when you place the ice cube and glass bottle (without the lid) into the container of water. Why do you think this will happen?
- Panel 7: Explain your observations using pictures and words. Include vocabulary words: heat transfer and convection. Make sure you show the direction of heat transfer in your panel.

Problem 4

- You want to see how heat transfers from a heat lamp to your hand and how this heat can be stopped from transferring using a Mylar sheet (Emergency Blanket). If Mylar sheet is not available use aluminum foil (Keep dull side of aluminum sheet towards source of heat in order to reflect back heat)

Instructions

- You will need a heat lamp and a Mylar sheet (emergency blanket). If Mylar sheet is not available use aluminum foil (Keep dull side of aluminum sheet towards source of heat in order to reflect back heat)
- Turn on the heat lamp and hold your hand about a foot from the lamp. Now, cover your hand with the Mylar sheet and observe.
- If you are having trouble, take a look at the video link below:
  http://dai.ly/x3fl1vi

Sharing Findings of Problem 4

- Panel 8: Explain your observations using pictures and words. Include vocabulary words: heat transfer and radiation. Make sure you show the direction of heat transfer in your panel.
- Panel 9: Use pictures and words to compare and contrast all three forms of heat transfer: conduction, convection, and radiation.
- Radiation explained:
  http://dai.ly/x3fki5z

Lesson 4 & 5– Engineering Design Challenge

Motivating and Engaging Context:

Almost everyone has experienced vaccinations, but why do we get them?
In Pakistan alone, 177 million of the 180 million population is at risk of malaria with 3.5 million confirmed cases of malaria each year most of them being young Pakistani children. With the most recent breakthrough in the worldwide efforts to fight against malaria, the European Medicines Agency (EMA) has approved the first malaria vaccine- also the first ever vaccine to provide protection from a parasite. Now, the biggest challenge is to store these vaccines at the correct temperature. Directorate of Malaria Control (DMC) at Islamabad has invited the schools to join hands in solving the challenge of storing and transporting the precious malaria vaccines at the correct temperature for 10+ days, even when the power is unreliable.

Lesson Plan (For Lesson 4 & 5)

Introduction:

1. Has anyone in here ever had measles, chicken pox or typhoid fever?
2. What are some of the things we can do to keep from getting these diseases?
3. Write the term "vaccine" on the board and draw KWL chart and elicit from students what they already know about vaccine; what they want to know and what they have learnt.
4. Watch "How vaccines work?"

http://www.dailymotion.com/video/x2ovrh1
So what else do we know about vaccines?
Guide discussion to remind students that vaccines are made from the real viruses, or at least parts of them.
When should someone get a vaccination- before, during or after being sick ? Why?
What do they think could happen if the vaccine were frozen or get too warm? Hold up an old milk carton. Ask for volunteers to smell as the teacher "wafts" the odor to them with a hand. ask:

a. What do you notice?
b. Why did that happen?

c. Note that vaccines also need to be kept cool so that they don't spoil. But not frozen otherwise it will destroy the vaccine.

Activity

1. What are some of the other diseases, besides measles, chicken pox etc that vaccinations protect against?
   One of them is Malaria-its vaccination has just been approved on September 1, 2015. Invite comments from students (what was happening earlier to protect people from malaria?)
2. Watch Geo tv report on malaria in Pakistan
   https://www.youtube.com/watch?v=SE945ZwsEik
   Who is most in danger from malaria? Why? (Children are weak and have low immunity to diseases)
   Ask students to read the given data and ask them to make claims using the evidence and provide explanation.

Engineering Design Challenge:

In these two lessons students will apply knowledge of heat and heat transfer from STEM unit "Cool It" using the Engineering Design Process.

1. Def**ine the Problem**-"Store malaria vaccines at the correct temperature"
   Our client, Directorate of Malaria Control (DMC) at Islamabad has invited the schools to join hands in solving the challenge of storing and transporting the malaria vaccines at the correct temperature for 10+ days, even when the power is unreliable.
   We, the engineers, have explored how heat moves from warmer areas/ materials into colder and materials that are conductors/insulators of heat.
2. **Explore the Problem**
   Read the article below on 'Vaccines- coming in from the cold' and also read 'Vaccine handling tips'
   http://www.gsk.com/en-gb/behind-the-science/access-to-healthcare/vaccines-coming-in-from-the-cold/
   http://www.medinahealth.org/images/company_assets/D98A6E31-3E37-43FF-BC1A-ECC84E8F1117/Vaccinehandlingtips_89f6.PDF
   Now watch the TED Talk below on 'A Mobile Fridge for Vaccines'
   https://www.youtube.com/watch?v=HSdXqmnNCp0
   Finally, watch the video below about 'Innovative storage device keeps vaccines fresh for up to 35 days'
   https://www.youtube.com/watch?v=rDM5QMNx6H8
3. **Plan a prototype vaccine cooler**
   Draw three possible models. Select the best model out of three.
   Remember:
   - Our vial of malaria vaccine is an 'ice cube'

- We are designing a cooler for this vial- ‘ice cube’
- We want our ‘ice cube’ to melt a little, so that we know our vaccine won’t freeze, but not too much so that w know that vial will stay cold
- Our vaccine cooler needs an opening so that we can get the vaccine in and out
- Our vaccine coolers would be tested under two 100 watt lamps in the “testing site”- a simulation for hot environment to which vaccine cooler would be exposed
- Our client, DMC wants our vaccine cooler designs to be low cost
- Think about good shapes and or sizes for our vaccine coolers

4. Design a prototype vaccine cooler –Ask students to plan the design within the following budget:
You are given a budget of Rs.100, so you will need to decide which materials are worth “purchasing”, keep a record and report the cost of your design. So you should first explore the insulating properties of your materials by testing the properties of the materials you are considering under a heat lamp

Sr.#	Materials	Size/quantity	Price list
1.	Regular aluminum foil	one 10 X 10 cm square	Rs. 1.00
2.	Heavy duty aluminum foil	one 10 X 10 cm square	Rs. 2.00
3.	Copy paper	one 10 X 10 cm square	Rs 2.50
4.	Printer paper	one 10 X 10 cm square	Rs. 3.00
5.	Wax paper	one 10 X 10 cm square	Rs. 1.00
6.	Foam	one 10 X 10 cm square	Rs. 8.00
7.	Felt	one 10 X 10 cm square	Rs. 8.00
8.	Bubble wrap	one 10 X 10 cm square	Rs. 6.00
9.	Plastic wrap(Cling sheet)	one 10 X 10 cm square	Rs. 1.00
10.	Paper towel	one 10 X 10 cm square	Rs. 1.00
11.	Cotton ball	each	Rs. 2.00
12.	Craft stick	each	Rs. 4.00
13.	Tape	one 10 cm piece	Rs. 1.00
14.	Plastic measuring cup(small)	each	free
15.	Vial of malaria vaccine-“ice cube”	each	free
16.	Scissors	each	free
17.	Glue	To be shared among groups	free
18.	Digital scale		free

You will be designing and building a technology- vaccine cooler that will keep a vial of malaria vaccine-(an ice cube) from melting in your “testing site”
To prepare your “testing site” – use the plastic storage container . Paint the bottom of the container black or cover with black paper. Line the sides of the inside of the box with aluminum foil. The first image shows three, but two heat lamps or desk lamps will work (100W bulbs) too. You can also use a “hot pot” instead of “plastic storage box”. Its up to to you what is easily available.

5. Test your prototype vaccine cooler

- Use plastic measuring cup (that comes with children’ cough syrup or equivalent) as the container that holds ice cube in

- Measure the starting mass of your ice cube
- Put the ice cube (still in plastic cup) in your vaccine cooler
- Place your vaccine cooler with ice cube into the testing site for 15 minutes
- Remove the ice cube from the vaccine cooler and weigh the ending mass of ice cube

6. Present your findings from engineering design challenge as a story board:

Panel 1 of your storyboard: share a picture or drawing of your design and explain your decisions

Panel 2 of your storyboard: share the existing work that would be helpful in this design challenge e.g. Potential hazards of exposing vaccine to warmer temperature or vise versa, ways of vaccine storage, some successful vaccine cooler designs

Panel 3 of your storyboard: share the cost of your design along with details of materials used. Discuss the success of your design. What might you change and why?

- Look at the variety of design approaches other teams have used to solve this engineering design challenge. Share out data with the whole class and discuss how could teams improve their designs of vaccine coolers.

In order to make a claim that your model vaccine cooler worked well, you need to gather following evidence:

- Starting mass of "ice-cube" in grams expressed both in decimal fraction and mixed number (e.g. 1.5 g and 1 $^{5}/_{10}$ g or 1 $^{1}/_{2}$ g)
- Ending mass of "ice-cube" in grams
- Difference in mass of "ice-cube" in grams after the test
- Table showing data of each team

Team Name	Starting Mass (gram) Decimal Fraction Mixed Number	Ending Mass (gram) Decimal Fraction Mixed Number	Mass Lost (gram) Decimal Fraction Mixed Number	Cost of Prototype

7. Re-design your model vaccine cooler

- Make revisions of design
- Retest
- Discuss possible redesigns for your vaccine cooler- be explicit about how your design addressed heat transfer through conduction, convection, and radiation. Use science vocabulary to explain your claims
- Discuss how you balance trade-offs of cost vs. design
- How would you assess your students?

Panel 4 of your storyboard: Share your findings from re-design of your new prototype.

- Examine new prototype and share;
- Did the new design address the shortcomings of design 1?

- Did the construction of design 2 make the cooler work better?
- Did the materials chosen for redesign improve the performance of the cooler?
- Did you lower the cost?

Closure:
Gallery walk: Each group will share their final design and the story board. Facilitate students to communicate their solution to the problem posed.

Assessment:
Each group would be assessed on their communication of engineering design and to what extent they design within the given constraints.

Appendix 3.7 Post Survey

1. To what extent the tasks/activities of oTPD-STEM helped you to understand integration of STEM?

Tasks of oTPD-STEM	Least effective	To some extent	Adequate	Effective	Highly Effective
Facebook group posts					
WhatsApp group chats					
WhatsApp individual chats					
Exemplar STEM unit					
Practice unit					
Video tutorials					
Short video clips					
Working individually					
Working in teams					
Written reflections					
Reflective conversations					
Planning STEM unit					
Implementing STEM unit					
Redesigning/adapting STEM unit					

2. What is your key learning that happened through participation in oTPD-STEM program?

3. Share an example to describe integration of STEM>

4. How did the flexibility of oTPD-STEM help/challenge you in participating in online teacher professional development?

5. If you were to do this kind of online teacher professional development again, what additional activities/approaches would you suggest?

Appendix 3.8-Individual Response Reflective Learning Protocol

Reflective Learning 1

Q1. Reflect on the exemplar STEM unit and share how did the unit go? What caused it to go that way?

Q2. How do you see "Claim, evidence and explanation model"? How was your experience similar or different to your students' response to this approach?

Q3. How do you see "Storyboard" approach? How was your experience similar or different to your students' response to this approach?

Q4. How do you see the role of "Claim, evidence and explanation model" and "Storyboard" in constructing explanations for science and engineering?

Q5. How has the implementation of exemplar STEM unit informed your current STEM integration perspective?

Reflective Learning 2

Q1. Can you explain how defining the problem in engineering design challenge is very important?

Q2. How did the constraints of the problem help or hinder students' learning during engineering design challenge facilitate/hinder students' learning?

Q3. How did the design and redesign phase of engineering design challenge facilitate/hinder students' learning?

Q4. What was the role of communication and teamwork during engineering design challenge (Reflect on exemplar STEM unit)?

Q5. What is your metaphor to describe engineering design challenge?

Reflective Learning 3

Q1. As you have watched the assigned videos, reflect on "scientific inquiry" and share what do you think about it?

Q2. Suggest a testable question that you would want to explore in your classroom using scientific inquiry as an instructional approach?

Q3. How can you practice scientific inquiry in your classroom? Elaborate with an example.

Q4. If you could adopt scientific inquiry approach to teaching science, how would it support or hinder integration of STEM?

Q5. What is your metaphor to describe "scientific inquiry"?

Reflective Learning 4

Q1. What do you think about existing perspectives on STEM integration?

Q2. Share your personal perspective on STEM integration.

Q3. How is your STEM model same or different from your current science teaching practices?

Q4. Now at the end of oTPD-STEM, what is your metaphor to describe STEM integration?

Q5. Reflect back on the learning focus of oTPD-STEM and comment on:

- Opportunities,
- Challenges,
- So now what? And,
- What next?

Appendix 4.1 Interview 2

1. Any idea that you want to continue from oTPD-STEM on Moodle 2.8 ?
2. What are your expectations from oTPD-STEM on Facebook?
3. What kind of activities would help you better understand STEM integration?
4. What is your preference for the science and mathematics content for STEM integration? And why?
5. What resources are needed to understand STEM integration?
6. What is the best time to begin oTPD-STEM on Facebook?

Appendix 4.2 Interview 3

General

Q1. How do you think the STEM unit- Cool It went?

Q2. How do you see STEM integration now in the light of this exemplar unit?

Exemplar STEM Unit Specific

Q3. How do you find **“Claim, evidence & Explanation”** approach for scientific inquiry? How was your own experience of using this approach? How was your experience different/similar to your students’ response?

Q4. When you reflect back, what would you do differently next time you use this approach?

Q5. How do you find **“Storyboard”** approach for scientific inquiry? How was your own experience of using this approach? How was your experience different/similar to your students’ response?

Q6. When you reflect back, what would you do differently next time you use this approach?

Q7. How do you find **“Engineering Design Challenge”** idea for exploring and solving a problem? How was your own experience of using **Engineering Design Process**? How was your experience different/similar to your students’ response?

Q8. How do you find **“Claim, evidence & Explanation” and “Storyboard”** in constructing explanations for science and solutions for engineering?

Q9. What do you think, would there be change in your STEM integration Visual now?

Appendix 4.3 Pre-Reflective Learning Team Conversation Tasks

Pre- Reflective Learning Team Conversation 1 Tasks

Task 1: Watch the video clip by the National Academies of Sciences, Engineering and Medicine titled "STEM Integration in K-12 Education"

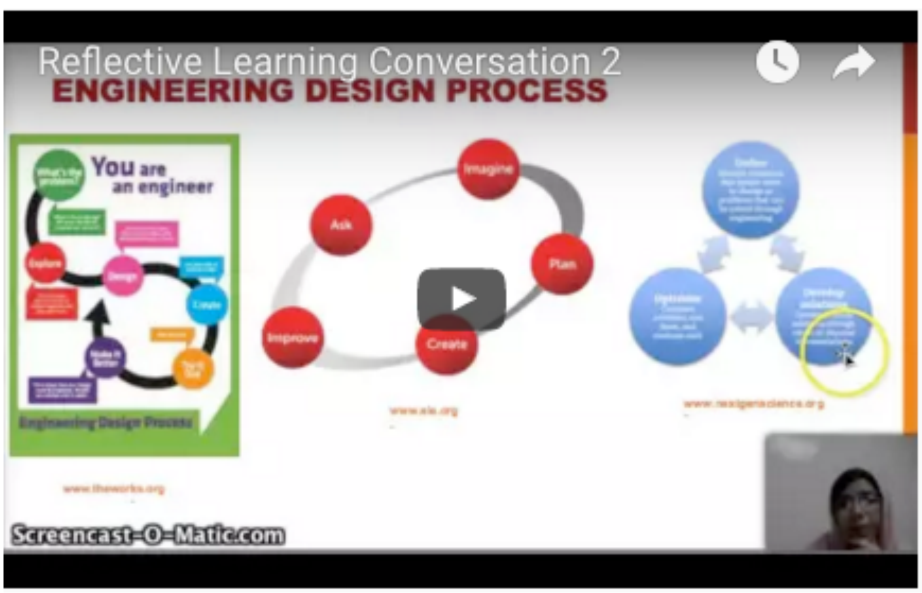
After watching the video clip by the National Academies of Sciences, Engineering and Medicine and think about what is integration of STEM.

Task 2: Watch the video tutorial on Research on Integration of STEM.

Watch After watching the video tutorial about research supporting integration of STEM, reflect upon your teaching and students learning while implementation of STEM exemplar unit during oTPD-STEM.

Pre- Reflective Learning Team Conversation 2 Tasks

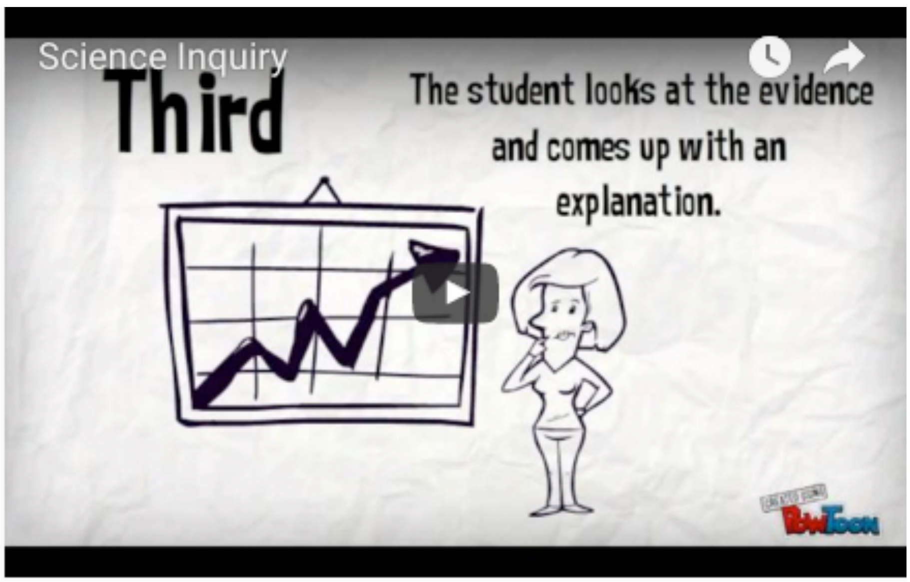
Task 1: Watch the video tutorial about research on "Engineering Design Process".

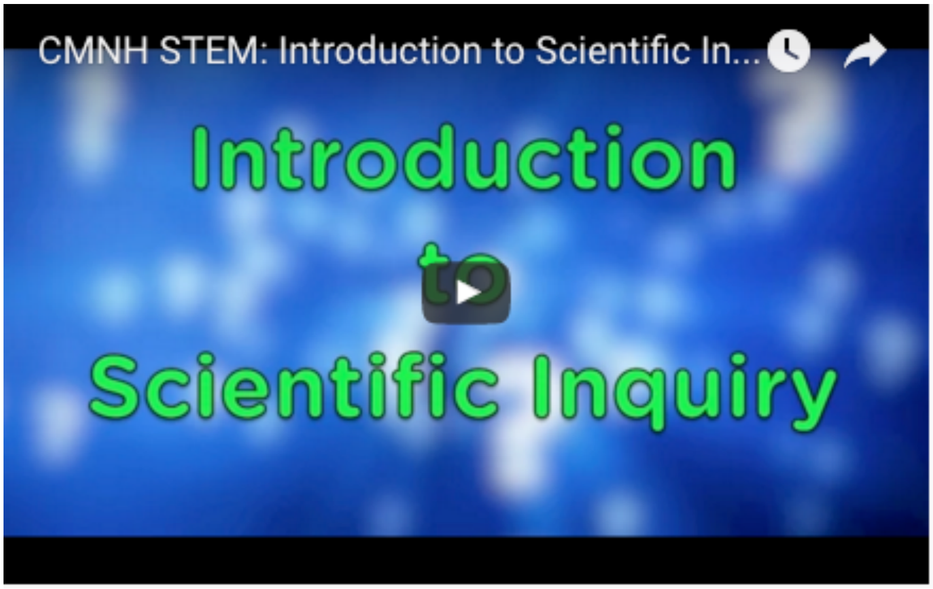


After watching the video tutorial about research supporting engineering design process and reflect upon your teaching and students' learning while implementation of STEM exemplar unit during oTPD-STEM

Pre- Reflective Learning Team Conversation 3 Tasks

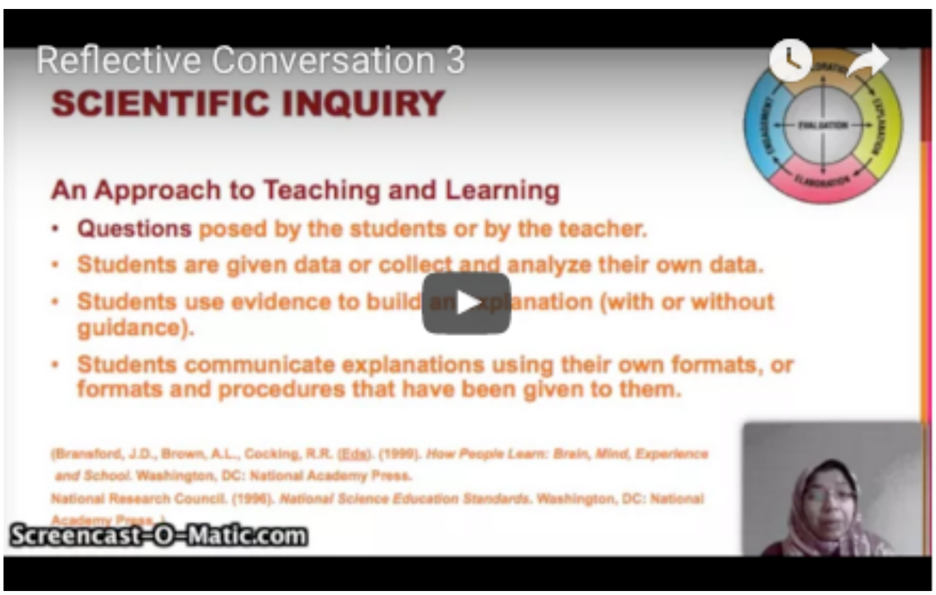
Task 1: Watch the video clips on Scientific Inquiry and its example.





After watching the video clips about scientific inquiry and its example, think about what is scientific inquiry?

Task 2: Watch the video tutorial about research on "Scientific Inquiry".



After watching the video tutorial about research supporting scientific inquiry and reflect upon your teaching and students' learning while implementation of STEM exemplar unit during oTPD-STEM

Pre- Reflective Learning Team Conversation 4 Tasks

Task 1: Watch the video tutorial about research on "Perspectives of Integration of STEM".

After watching the video tutorial about research on "Perspectives of Integration of STEM", reflect on:

1) Your personal perspective about integration of STEM and
2) The key components of this oTPD-STEM program;
    (a) Online learning environment and
    (b) Learning focus on integration of STEM.