NİL ŞENKUTLU

A SYSTEMATIC ANALYSIS OF AN INITIAL STEM PROFESSIONAL DEVELOPMENT PROGRAM: A CASE STUDY

MASTER'S THESIS

BY

NİL ŞENKUTLU

THE PROGRAM OF CURRICULUM AND INSTRUCTION
İHSAN DOĞRAMACI BILKENT UNIVERSITY
ANKARA

DECEMBER 2018

2018

Annem ve anneanneme...

A SYSTEMATIC ANALYSIS OF AN INITIAL STEM PROFESSIONAL DEVELOPMENT PROGRAM: A CASE STUDY

The Graduate School of Education

of

İhsan Doğramacı Bilkent University

by

Nil Şenkutlu

In Partial Fulfillment of the Requirements for Degree of

Master of Arts

in

Curriculum and Instruction

Ankara

December 2018

İHSAN DOĞRAMACI BILKENT UNIVERSITY

GRADUATE SCHOOL OF EDUCATION

A SYSTEMATIC ANALYSIS OF AN INITIAL STEM PROFESSIONAL DEVELOPMENT PROGRAM: A CASE STUDY

Nil Şenkutlu

December 2018

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Arts in Curriculum and Instruction.

Asst. Prof. Dr. Armağan Ateşkan

(Supervisor)

Assoc. Prof. Dr. M. Sencer Çorlu,

Bahçeşehir Un. (2nd Supervisor)

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Arts in Curriculum and Instruction.

Asst. Prof. Dr. Zerrin Doğança Küçük, Bahçeşehir Un. (Examining Committee Member)

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Arts in Curriculum and Instruction.

Prof. Dr. Alipaşa Ayas (Examining Committee Member)

Approval of the Graduate School of Education

Prof. Dr. Alipaşa Ayas (Director)

ABSTRACT

A SYSTEMATIC ANALYSIS OF AN INITIAL STEM PROFESSIONAL DEVELOPMENT PROGRAM: A CASE STUDY

Nil Şenkutlu

M.A., Program of Curriculum and Instruction

Supervisor: Asst. Prof. Dr. Armağan Ateşkan

2nd Supervisor: Assoc. Prof. Dr. M. Sencer Çorlu

December 2018

The aim of this case study was to gain a better understanding of how an initial STEM (Science, Technology, Engineering, and Mathematics) professional development (PD) program implemented on a specific group of mathematics and science teachers and examine these mathematics and science teachers' understandings and perceptions of STEM education and their influence on classroom practices. This study was framed and guided by STEM: Integrated Teaching Framework (InTeachFramework) which also formed the "focal points" of this study that were interdisciplinarity, rigor, relevance, and equity.

In this exploratory case study, qualitative data gathered by observing the initial STEM PD program for 27 secondary mathematics and science teachers within a large metropolitan school. Voice records and written data were utilized with observational techniques to determine perceptions and influences of STEM education on teachers.

Findings indicated that initial STEM PD provided teachers to show their general understanding on STEM principles explicitly in their classroom practices. Real-life applications related to teacher's main disciplines and connections of them with other disciplines were the most adopted indicators in the classrooms. Similarly, teachers gained an understanding on necessity of authentic problems of knowledge society (APoKS) for teachers in school environment. The study also found that the desired solution offers and related products for APoKS that emphasized in STEM PD were not fulfilled in the classroom practices.

Key words: STEM, STEM education, integrated teaching, teacher professional development

ÖZET

BAŞLANGIÇ FeteMM (STEM) MESLEKİ GELİŞİM PROGRAMININ

SİSTEMATİK ANALİZİ: DURUM ÇALIŞMASI

Nil Şenkutlu

Yüksek Lisans, Eğitim Programları ve Öğretim

Tez Yöneticisi: Dr. Öğr. Üyesi Armağan Ateşkan

2. Tez Yöneticisi: Doç. Dr. M. Sencer Çorlu

Bu durum çalışmasının amacı STEM [Fen (Science), Teknoloji (Technology), Mühendislik (Engineering), ve Matematik (Mathematics)] temelli başlangıç mesleki gelişim programının nasıl uygulandığını tanımlayarak, belirli bir grup lise matematik ve fen öğretmenlerinin STEM eğitimi anlayışlarına, algılarına ve sınıf uygulamalarına olan etkilerini incelemektir. Bu araştırma, aynı zamanda çalışmanın "odak noktalarını" -disiplinlerarasılık, derinlik, ilgililik, ve eşitlik- oluşturan STEM: Bütünleşik Öğretmenlik Çerçevesi tarafından şekillenmiş ve yönlendirilmiştir.

Bu keşifçi durum çalışmasında, büyük bir metropol okulda çalışan 27 lise matematik ve fen öğretmenlerine uygulanan başlangıç STEM mesleki gelişim programı gözlemlenerek nitel veriler toplanmıştır. Ses kayıtlarından ve yazılı verilerden, öğretmenlerin, aldıkları STEM eğitimini nasıl algıladıkları ve etkilerini belirlemek adına gözlem tekniklerinden yararlanılmıştır.

Bulgular, STEM mesleki gelişim programının öğretmenlere, STEM prensipleri hakkındaki genel anlayışlarını sınıf uygulamalarında açıkça göstermelerini sağlamıştır. Öğretmenlerin ana disiplinleri ile ilgili gerçek yaşam uygulamaları ve bu uygulamaların diğer disiplinler ile bağlantıları, sınıflarda en çok kullanılan göstergelerdir. Benzer şekilde, öğretmenlerin okul ortamında bilgi temelli hayat problemi [BTHP (APoKS)] gerekliliğine dair bir anlayış kazandıkları belirlenmiştir. Çalışma, diğer bir yandan, STEM mesleki gelişim programında vurgulanan BTHP için istenen çözüm önerilerinin ve ilgili ürünlerin üretilmesinin sınıf uygulamalarında yerine getirilmediğini de ortaya koymuştur.

Anahtar kelimeler: STEM, STEM eğitimi, bütünleşik öğretmenlik, öğretmen mesleki gelişim

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my supervisor Asst. Prof. Dr. Armağan Ateşkan for her valuable guidance, expertise, consideration, encouragement and patience. Without her guidance and help, this master's thesis would not have been possible. Also, I would like to thank my co-supervisor, Assoc. Prof. Dr. M. Sencer Çorlu for all the opportunities he provided during my thesis writing process. This thesis would not be comprehensive enough without him. Further, I humbly wish to extend my thanks to Prof. Dr. Alipaşa Ayas and my committee member Asst. Prof. Dr. Zerrin Doğança Küçük for all their valuable feedback. Also, my great respect goes to all my instructors at Graduate School of Education who made a great effort to raise highly qualified teachers.

I would like to acknowledge and thank my school MYP coordinator and my dearest friend Dr. Servet Altan for helping me every step and sharing his expertise with his endless motivation and support. Thank you to my dearest teacher colleagues, İlksen Sevil Uluçay and Mehtap Hacıislamoğlu. They have provided great company and encouragement during this process. On this occasion, my sincere thanks to all my teacher colleagues at my school and my friends for all their words and acts of encouragement throughout this process.

Lastly but certainly not the least, I would like to extend my deepest appreciation to my lovely family. Especially, my mother Nihal Kanevetçi for her unwavering love and support during my whole education journey.

TABLE OF CONTENTS

ABSTRACT iii

ÖZET iv

ACKNOWLEDGEMENTS v

LIST OF TABLES xii

LIST OF FIGURES xiii

LIST OF ABBREVIATIONS xiv

CHAPTER 1: INTRODUCTION 1

Introduction 1

Background 1

STEM education and professional development 6

Problem 7

Purpose 8

Research questions 8

Significance 9

Definitions of key terms 10

CHAPTER 2: REVIEW OF RELATED LITERATURE 12

Introduction 12

Teacher quality 12

Characterization of teacher quality 12

Teacher quality in Turkey 15

Ideas on improving teacher quality 17

Professional development of mathematics and science teachers 17

Evolution of teacher professional development 17

Effect of professional development on teacher quality for mathematics and science teachers 20

Need for a professional learning community in teacher education 22

STEM education 24

Overview of STEM education: Then and now 25

Conceptual framework for the study 26

The role of professional development in STEM education 30

CHAPTER 3: METHOD 33

Introduction 33

Research design 33

Context 34

STEM professional development process 35

Participants 35

Instrumentation.. 36

Observation forms 36

PD seminar- workshop observation form 36

Professional learning community meeting observation form 37

Classroom practice form 37

Voice recordings.. 38

Workshop research-record book.. 38

Teachers' reflections.. 38

STEM lesson plan preparation guide.. 38

Method of data collection.. 39

STEM professional development seminars -workshops.................................... 40

Professional learning community meetings.. 40

Teachers' reflections.. 41

Classroom practices of teachers.. 41

Methods of data analysis 42

Trustworthiness.. 44

CHAPTER 4: RESULTS 47
Introduction 47
Findings of the study 47
Description of the initial STEM PD program 48
Module 1 –Interdisciplinarity 49
Module 2 –Rigor in main discipline 50
Module 3–Relevance to authentic problems of knowledge society 52
Module 4–Assessment 54
Module 5–Discourse-Argumentation 54
Findings related to the contribution of PD based on STEM to the classroom practices of secondary mathematics and science teachers. 57
Interdisciplinarity 57
Rigor 60
Relevance 64
Equity 68
Approaches to authentic problems of knowledge society (APoKS) 70
Findings related to the contribution of PD based on STEM to the teaching philosophy of secondary mathematics and science teachers according to their perception. 71

Interdisciplinarity 72

Rigor 73

Relevance 74

Equity 75

Approaches to authentic problems of knowledge society (APoKS) 76

CHAPTER 5: DISCUSSIONS 78

Introduction 78

Overview of the study 78

Major findings 79

STEM principles and teachers' classroom practices 79

Development of interdisciplinarity, rigor, and real-life application through STEM PD 80

Attitudes towards implementation of an authentic problem of the knowledge society in the classroom 80

Discussion of major findings 81

STEM principles and teachers' classroom practices 81

Development of interdisciplinarity, rigor, and relevance applications through STEM PD 83

Attitudes towards implementation of an authentic problem of the knowledge society in the classroom 84

Implications for practice 85

Implications for further research 86

Limitations 87

REFERENCES 88

APPENDIX A: PD Seminar-Workshop Observation Form 100

APPENDIX B: PLC Meeting Observation Form 101

APPENDIX C: Classroom Practice Form 102

APPENDIX D: STEM Lesson Plan Preparation Guide 103

APPENDIX E: Workshop Research-Record Book 105

LIST OF TABLES

Table Page

1 The competences of teachers: Perspectives from research and policy........ 14

2 STEM PD program data collection.. 39

3 PD seminar-workshop 48

4 Indicators of focus topics... 55

5 Distillation of indicators under the focal points.. 56

6 Indicators that were stated in reflections... 72

LIST OF FIGURES

Figure Page

1 STEM: Integrated Teaching Framework.. 28

2 Elements of Trustworthiness... 44

LIST OF ABBREVIATIONS

APoKS……………….………..…...Authentic problem of knowledge society

ETS………………………………Educational Testing Service

HEC……………………………...Higher Educational Council

IB DP…………………………....International Baccalaureate Diploma Program

InTeachFramework……………...Integrated Teaching Framework

MoNE……………………………Ministry of National Education

NCLB……………………………No Child Left Behind

NCTAF…………………………..National Commission on Teaching & America's Future

NPEAT…………………………..National Partnership for Education and Accountability in Teaching

NSF……………………………...National Science Foundation

PBL..Project –based learning

PCK……………………………...Pedagogical content knowledge

PD………………..........................Professional development

PLC………………………………Professional learning communities

OECD……………………………Organization for Economic Co-operation and Development

STEM…………………………….Science, technology, engineering, matematics

TALIS……………………………Teaching and Learning International Service

CHAPTER 1: INTRODUCTION

Introduction

This chapter provides a review of teacher quality and student achievement in Turkey by examining the main characteristics of educational reforms related to teaching practices. It focuses mainly on mathematics and science teachers' adaptations and progress on how they integrate STEM (Science Technology, Engineering and Mathematics) subjects into their teaching practices. More specifically, this study investigates the impact of an initial STEM Professional Development (PD) program by examining whole process in the program and teachers' classroom practices.

Background

In today's global world conditions, the importance of the quality of education is on the increase directly related with the need of quality of labor force (İlğan, 2013; Ozoglu, 2010). One of the most important components for development of a society is the quality of education that citizens acquire and teachers play an important role in the overall quality of teaching and learning in schools. Considering National Commission on Teaching and America's Future's (1996) and National Education Goals Panel's (1996) standards for student learning, greater attention has been given to teacher quality since it plays an important role in student achievement (Darling-Hammond, 2000). As it is stated in European Commission (2012) teachers and teaching professionals are the key and essential determinants of improving the performance of students. Hopkins and Stern (1996) claimed that any benefits that have an effect on students under the educational policies depend on the actions of teachers. Hopkins and Stern also identified the main characteristics of high-qualified teachers as commitment, expertise on their subjects, skills in using variety of teaching models, the ability to collaborate with other teachers, and ability to do reflection.

Considering National Commission on Teaching and America's Future's (1996) and National Education Goals Panel's (1996) standards for student learning, greater attention has been given to teacher quality since it plays an important role in student achievement (Darling-Hammond, 2000). As it is stated in European Commission (2012) teachers and teaching professionals are the key and essential determinants of improving the performance of students. For similar reasons, teacher quality in Turkey may be considered as an indication of educational success.

Several international studies emphasized that effective schools have qualified teachers (Naylor & Sayed, 2014). More than a decade, developed and developing countries have interested in particularly how to improve teacher quality and curriculum design (Systems Approach for Better Education Report [SABER], 2012). As a member of The Organization for Economic Co-operation and Development (OECD), Turkey is no different from these countries that need qualified teachers. OECD conducts TALIS (Teaching and Learning International Service)— the first, largest, and most extensive international survey of teachers, surveying lower secondary teachers and their school leaders around the world— for example, it provides detailed findings about the continued need for innovative teachers across countries. According to the school principals' reports in undated TALIS; teachers in Turkey have more weaknesses in their work disciplines which consist of arriving late at school, absenteeism, and lack of pedagogical preparation. Especially, 43% of school teachers in Turkey have reported a lack of pedagogical preparation, which may show they do not know or use a variety of teaching methods. On the other hand, the average of the other OECD member countries is only 24% in TALIS. Quality of teacher is not a stable matter when a teacher starts this profession; from experience, ongoing PD programs which include in-service training workshops and professional support that provides school-based mentoring and teacher study groups (Naylor & Sayed, 2014). PD is grounded in teachers' defined needs and it composed of comprehensive, sustainable and systematic learning experiences. Furthermore, it requires improving student success and performance outputs and concluded with educational effectiveness (İlğan, 2013).

There are different types of PD undertaken by teachers such as, courses and workshops, education conferences and seminars, qualification problems, and individual and collaborative research (Darling-Hammond, 2000). When looking at the impacts of different types of PD undertaken by teachers in OECD results between 2007-2008 years; courses and workshops have the least effect on teacher comparing the other types of PD. This indicates that because of the lack of PD courses and workshops, teachers in Turkey do not benefit effectively from their PD. The percentage of teachers in Turkey who took PD between 2007-2008 education years is below the TALIS average, which also indicates a need for PD in Turkey to increase the overall quality of teaching. Turkey did not participate in 2013 OECD and 2018 OECD research in terms of teacher quality. Furthermore, it is hard to say that there is conformity between effective PD activities that are specified within the scope of the literature discussions and the PD activities in Turkey (İlğan, 2013). Thus, regarding teachers' PD needs, decision makers and professionals must support and embolden the participation of teachers effectively and be sure that the given PD matches teachers' main needs (OECD, 2009). Considering Hopkins and Stern's (1996) report on main characteristics of high-quality teachers and the overall OECD results between 2007-2008 years; teachers in Turkey do not effectively fulfill the teacher quality requirements.

Teacher quality should be increased through classroom experiences and also by teachers taking serious PD courses. According to OECD (2009) the PD of teachers apart from their initial training should meet the following objectives:

- to update individuals' knowledge of a subject in light of recent advances in the area;
- to update individuals' skills, attitudes and approaches in light of the development of new teaching techniques and objectives, new circumstances and new educational research;
- to enable individuals to apply changes made to curricula or other aspects of teaching practice;
- to enable schools to develop and apply new strategies concerning the curriculum and other aspects of teaching practice (p. 49).

When PD targets specific teaching practices, it is likely to show an upturn in the implementation of those practices by teachers in their classrooms (Desimone et al., 2002). Depending on the global developments in science and technology, rapid changes are observed in social, economic and cultural fields and in education which is an important part of these fields (Ozoglu, 2010). So, curriculum and teaching methods, which are used in schools, are influenced directly by these developments. Regarding these changes, teacher's duty, role and responsibility show alterations. In this concern, although stakeholders including parents, students, administrators, organizations may have different point of views on how the education system should work, they all agree upon the importance of teacher education in terms of embracing these rapid changes (Ozoglu, 2010).

If teachers took PD with their colleagues from their school, department, or grade level, effectiveness of the PD were high in terms of teachers' performances (Desimone et al., 2002). Within this respect, collaboration among teachers provides a route for improvement (Berry, 2015). Research suggested that students get higher scores on achievements tests when their teachers collaborate and work with their colleagues over long periods and share their knowledge and experiences mutually (Jackson & Bruegmann, 2009). With this regard, PLCs become a need especially for mathematics and science teachers by leading them on how to do efficient collaborations and interactions with their colleagues within disciplinary or interdisciplinary fields. For science teachers, PLCs have direct effects on their pedagogical content knowledge and disciplinary content knowledge. Also interaction among science teachers during PLCs provides them more effective teaching techniques in the lessons. A powerful change can be observed in science teachers' practices who have participated in well-organized PLCs; they did more student-centered and inquiry-based approaches (Dogan, Pringle, & Mesa, 2015). It is claimed that particularly effective research-based PD on project-based learning and PLCs led to recognizable student learning gains, on the high-stake exams. Furthermore, it was reported that if the school administration supported teachers about PLCs, Mathematics and Science teachers' behaviors and their implementations of project-based learning in the classroom showed improvement which directly and positively affected students' learning (Capraro et al., 2016).

STEM education and professional development

STEM education was engendered by the needs of educating students for 21st century needs (Akaygun & Aslan-Tutak, 2016). STEM education, which integrates skills, knowledge and attitudes specific to each discipline in a coherent way, requires a new approach to teaching and learning mathematics and science (Corlu, Capraro, & Capraro, 2014). It contains not only mathematics and science, but also technology and engineering disciplines that are the needed necessary skills for the future jobs (Roberts, 2013b).

During the current knowledge era, people "are required to be literate in STEM disciplines, think interdisciplinary and work collaboratively to solve complex real-world problems (e.g. environmental problems) and take action in practical applications" (Akaygun & Aslan-Tutak, 2016, p. 57). Therefore, it is crucial to discover how teachers can teach integrated STEM education in their classrooms efficiently (Stohlmann, Moore, & Roehrig, 2012). However, one of the most challenging expectation of STEM education is the integration of these various disciplines in order to solve authentic problems (Hernandez et al., 2014; Labov, Reid, & Yamamoto, 2010; Sanders, 2009). In order to help teachers equip their students with the skills required to be successful in the 21st century, professional development about STEM education can help to increase the overall teacher quality in Turkey. Therefore, Mathematics and Science teachers' PD and participation in PLCs related to STEM education can be a necessity in order to be qualified in STEM disciplines and to create authentic problems.

Problem

Even though there have been studies related to in-service teacher training under different titles by Ministry of National Education in Turkey (MoNE) for years, low teacher quality is still an ongoing serious issue in Turkey. MoNE provides in-service trainings through courses and seminars to teachers under the name of program-improvement. However, these courses and seminars have not led teachers to improve themselves effectively. One of the reasons is that MoNE prefers theoretical PDs rather than practical PDs for teachers which do not lead teachers to apply these theories actively in their lessons (Ozoglu, 2010). In the official website of MoNE, it is stated that for in-service teachers, PDs are generally conducted just before and/or after the education year. So, it is uncertain that whether teachers reflect their acquired knowledge in their lessons during the education year. Although PDs that are undertaken by teachers may have positive impacts on them, PD experts' lack of observations and process monitoring on teachers' professional development may cause a sense of less responsibility on teachers.

The ongoing high-stakes national exams are found to be conducive to traditional teaching which leads a routinized lesson for both teacher and student (Corlu et al., 2014). Preparing students to national exams may also cause hesitation in collaborating with colleagues among teachers as they try innovative and different techniques in their lessons. In order to encourage mathematics and science teachers to apply new techniques in their lessons, some responsibilities should be taken by school principals and administrators who need to give opportunities to attend effective and long-term PD and PLCs.

Purpose

The purpose of this qualitative study is to gain a better understanding of the impact of an initial STEM PD program implemented on a specific group of mathematics and science teachers. Firstly, the researcher described an initial STEM PD program that was conceptualized under STEM: Integrated Teaching Framework (InTeachFramework). Then it was aimed to explore the effects of this initial STEM PD program on participant mathematics and science teachers by specifically examining their classroom practices and teachers' reflections on STEM education. Data were gathered from STEM PD seminars, PD workshops, PLC meetings, teacher reflections, and classroom observations.

Research questions

The principles of STEM education in Integrated Teaching Framework (InTeachFramework) became the focal points of this research study. These focal points were interdisciplinarity, rigor, relevance, and equity. During the research process, these focal points transformed into the following research questions;

1. How can this initial STEM PD program be described?
2. How does the initial STEM PD affect the classroom practices of mathematics and science teachers?
3. What are the indicators that affect mathematics and science teachers' teaching philosophy according to their perception after taking the initial STEM PD program?

Significance

STEM education and related PD and PLC programs are developed and applied in countries with global strong economies which place in United States and European Union (Akaygun & Aslan-Tutak, 2016; MoNE, 2016; Corlu et al., 2014). Considering STEM education's outcomes on student learning and teachers' effectiveness; teachers and administrators from other nations are becoming interested in STEM education. In United States, every state integrates STEM subjects into their teaching practices, and their curriculums respectively (Dugger, 2010). Also European countries attempted to reform their STEM curricula by implementing courses to encourage digital skills and increase popularity of STEM studies and careers (European Schoolnet, 2018). Similarly, Turkey is one of these nations where there is a growing interest in STEM (Akaygun & Aslan-Tutak, 2016). A few private schools in Turkey are embedded STEM into their curriculums by implementing related PD and PLC programs to their teachers. Nevertheless, "As a developing country, Turkey has to provide big leap in STEM areas" (as cited in Akaygun & Aslan-Tutak, 2016, p. 58).

Considering the teacher quality improvement level and process, many research studies indicate significant results about the positive changes in teachers who qualified with integrating STEM education into their lessons. Increments and improvements in teachers' pedagogical content knowledge, preparation to the course contents and their approaches towards new teaching methods have been observed (as cited in NCTAF, 2010). Regarding STEM education in Turkey, there are also studies that focus on STEM education and its positive effects on mathematics and science fields in the schools (Aşık, Doğança, Helvaci, & Corlu, 2017; Akaygun & Aslan-Tutak, 2016; Corlu et al., 2014).

Teaching reform efforts in the United States have often shown only short-term effects on mathematics and science teachers (Oehrtman, Carlson, & Vasquez, 2009). The situation is similar in Turkey as educational reform efforts have not deeply affected educational practices (Aksit, 2007). One of the reasons for this problem can be that teachers do not engage in career-long learning in their school (Oehrtman et al., 2009). This study aims to explore the impact of an initial STEM PD program which was done in Turkey under the leadership of a STEM expert facilitator and his team. Finally, information acquired from this study could assist stakeholders regarding the potential expectations related to STEM PD and PLC programs. It would serve as a guideline not only for the stakeholders, but also for the researchers interested in STEM PD - PLC programs and their effects on mathematics and science teachers.

Definitions of key terms

Professional Development (PD): Professional development is defined as those processes and activities designed to enhance the professional knowledge, skills, and attitudes of educators so that they might, in turn, improve the learning of students (Guskey, 2000, p. 16).

Professional Learning Community (PLC): Professional learning communities has been used to describe virtually any loose coupling of individuals who share a common interest in education. The very essence of a learning community is a focus on and a commitment to the learning of each student. There is no ambiguity regarding the commitment to learning, and not just the learning of students. Adults in a learning community are continually learning (DuFour, DuFour, Eaker, & Many, 2006, p. 3).

STEM: STEM is an acronym for Science, Technology, Engineering and Mathematics, originally used by the education-related programs of the National Science Foundation (NSF).

Collaboration: In a PLC, collaboration represents a systematic process in which teachers work together interdependently in order to impact their classroom practice in ways that will lead to better results for their students, for their team, and for their schools (DuFour et al., 2006, p. 3).

CHAPTER 2: REVIEW OF RELATED LITERATURE

Introduction

This chapter provides a review of literature related to teacher quality, professional development, professional learning communities, and STEM education respectively. First section examines the teacher quality under four subsections; characterization of teacher quality, the teacher quality in U.S. and Turkey, and the possible ideas on improvement of teacher quality based on the reviewed literature. The second section reviews the literature on professional development for mathematics and science teachers by initially reviewing the literature on evolution of PD and then the effects of PD on mathematics and science teachers. The third section aims to provide review of the literature on professional learning communities. In the fourth section, it lastly describes the STEM education by giving the historical overview of STEM education and conceptual framework of this study mainly in the context of the PD and PLC literature.

Teacher quality

Characterization of teacher quality

A teacher's most significant responsibility is contributing to and improving the learning and success of the students (ETS, 2004). Teachers do not enter the classroom as finished products; within time, if they stay in the profession, they may improve their teaching skills over time. During the first meetings with the class, new teachers do not display their knowledge and educational skills adequately. However, with experience, practice, assistance, and training they become much more effective and qualified teachers than their novitiates (ETS, 2004). Hanushek (2002), on the other hand, stated that over the past 35 years two clear results revealed from the extensive research about the importance of teacher quality. First, there are significant differences among teachers and their attitudes in the classrooms. Second, these differences cannot be notified by common measures of teachers such as qualification, experience and so on.

Qualification of teacher changes according to educators' point of views and concerns. Strong (2011) explained this as;

> Definitions may be grouped broadly according to whether they focus on the qualifications of the teacher as a reflection of competence (e.g., degree, quality of college, exam scores, certification, subject-matter credential, experience), the personal or psychological qualities of a teacher (such as love of children, honesty, compassion, fairness), the pedagogical standards that a teacher exhibits (use of certain teaching strategies, classroom management skills, establishment of a positive classroom climate), or the teacher's demonstrated ability to raise student learning (successful or effective teaching). (p. 12)

The teacher educators, who support educational reforms, are likely to think about quality of teachers only related with classroom practices rather than personal attributes that a teacher might hold (Strong, 2011). Hopkins and Stern (1996) stated that qualified teacher has applied her/his own tactics for teaching concepts, skills, and information. Additionally, he/she has enhanced a theoretical and practical understanding of pedagogical models or philosophies.

According to some teacher educators, being a good teacher is combination of personal attributes consist of caring children and professional attributes that are related to pedagogical knowledge (Strong, 2011). For example, Darling-Hammond

(2000) defends a teacher's academic aptitude, years of education, professional seniority, level of pedagogic and content knowledge, certification status and behaviors towards students in the classroom can be seen as variables that help measuring the teacher competence and quality in terms of student learning. In consideration of the above discussions related to teacher quality and teacher competence, European Commission (2013, pp. 45-46) defines teacher competence under three main titles in Table 1.

Table 1
The competences of teachers: Perspectives from research and policy

Knowledge and understanding	Skills	Dispositions: beliefs, attitudes, values, commitment
•subject matter knowledge •pedagogical content knowledge (PCK) •pedagogical knowledge •curricular knowledge •contextual, institutional, organizational aspects of educational policies-issues of inclusion and diversity •effective use of technologies in learning •developmental psychology •group processes and dynamics, learning theories, motivational issues •evaluation and assessment processes and methods	•planning, managing and coordinating teaching •using teaching materials and technologies •managing students and groups •collecting, analyzing, interpreting evidence and data for professional decisions and teaching/learning improvement •using, developing and creating research knowledge to inform practices •collaborating with colleagues, parents and social services •negotiation skills •reflective, metacognitive, interpersonal skills for learning individually and in professional communities	•epistemological awareness-teaching skills through content-transferable skills •dispositions to change, flexibility, ongoing learning and professional improvement, including study and research-commitment to promoting the learning of all students •dispositions to promote students' democratic attitudes and practices-critical attitudes to one's own teaching (examining, discussing, questioning practices) •dispositions to team-working, collaboration and networking •sense of self-efficacy

Dividing teacher competence, which is constitutively dynamic and holistic, into main titles provide a detailed analytical understanding of underlying implications and assumptions.

Under knowledge and understanding category, pedagogical content knowledge (PCK) infers profound knowledge in content and structure of the subject matter that implies knowledge of tasks, learning outcomes, students' prior knowledge and learning difficulties related to subject-specific, and strategic knowledge of instructional approaches and curricular tools. On the other hand, pedagogical knowledge includes solely knowledge of teaching and learning processes (European Commission, 2013). Reflective, metacognitive, interpersonal skills for learning individually and in professional communities can be seen as skills that teachers need to adapt educational contexts which are characterized by various influences in their classrooms (European Commission, 2013).

Teacher quality in Turkey

Teachers are the main part in implementation of the educational policies; they are the integral part in educational policies with their implementations in classroom in order to raise productive individuals for society (Tarman, 2010). Teacher quality has been a national and international concern over the years. After the visit to Turkey in summer 1924, John Dewey (1859-1952), who has distinguishing, remarkable and still influential contributions to education, wrote a report about Turkish education system and made some recommendations on how to improve quality of education (Alptekin, 2006; Corlu, 2018; Turan, 2000). In his report, Dewey emphasized the importance of teacher development by acquainting them with the most progressive and efficient pedagogical methods that are used in other countries (Turan, 2000; Alptekin, 2006). Not in immediate, but in time Dewey deeply influenced many Turkish educators, and his ideas were influential in the establishment of 'village institutes' ten years after his visit (Turan, 2000; Alptekin, 2006; Corlu, 2018).

In parallel with the developments in technology, rapid changes in education have started in Turkish society like in other nations (Tarman, 2010). In 1981, associated with the foundation of Higher Educational Council (HEC), the main change has started (Aksit, 2007; Grossman, Sands, & Brittingham, 2010; Tarman, 2010). This council provided integrating of all academies and teacher training institutions into universities. HEC, designated the requirements of the academic staff promotions and determined the standards for university degrees (Grossman, Sands, & Brittingham, 2010; Tarman, 2010). In general, transformations in Turkish higher education system including teacher education programs and institutions between the years 1980-2010 by the council of HEC helped Turkey to develop and adapt them to European Union (EU) educational standards (Cetinkaya, 2014; Tarman, 2010).

Although reconstruction in the education programs and institutions, there are certain apprehensions about the quality of teachers and higher education institutes that train teachers. Ministry of Education provides “program development” courses and seminars to both pre-service and in-service teachers. However, teachers have no permission to design their own programs and to apply these programs. Moreover, the courses are submitted to teachers as pocket programs which do not lead teacher to be specialized. In order to end the teacher shortage for some subject areas, the graduates from unrelated departments by taking short-term initial teacher training were assigned. These sorts of implementations negatively affect not only the quality of education, but also the statue and prestige of teaching profession (Ozoglu, 2010).

Ideas on improving teacher quality

Teachers should be flexible in changing their own philosophy. Teachers not only have the ability to improvise, but also they approve and embrace the sustained change (Hopkins & Stern, 1996). Even though most of the teachers are working too much to do their utmost, there is lack of encouragements and incentives to improve their quality (Hanushek, 2002).

In the United States, an educational act called No Child Left Behind (NCLB) project was applied in 2001. In this project, all states were expected to make their teachers highly qualified in the schools through 2005-2006 academic years (Strong, 2011). According to NCLB act, teachers must have three characteristics in order to be highly qualified; initially they must have a bachelor's degree, must be licensed or certified by the state, and must exhibit subject matter competence in each academic subject they teach (ETS, 2004). Considering the present education system; to be a highly qualified teacher, teachers must follow the developments in education in global scale continuously. For this purpose, in Turkey teacher education programs need some reforms that adjust the teacher preparation methods to the demands of society (Tarman, 2010). In that sense, within tens of variables influenced the student learning process in educational system, teacher quality and the PD activities presented to teachers become more of an issue (İlğan, 2013).

Professional development of mathematics and science teachers

Evolution of teacher professional development

Teachers' capacities and knowledge are changing based on the new strengths and needs of the society (Hopkins & Stern, 1996). Education reforms related to student achievement bring direct needs of changing and rebuilding the very foundation of teachers' and principals' thinking about teaching and learning (NPEAT, 2000). To respond to these changes a diversity of lists of principles on effective professional development (PD) have developed (Orrill, Geisler, Brown, & Brunaud-Vega, 2008). Professional development refers to the designed processes and activities in order to enhance the professional knowledge, skills, and attitudes of teachers so that they might, as a result, improve the learning of students (Guskey, 2000). These new knowledge and beliefs based on research and practice also shape educators' way of thinking about teacher PD (Loucks-Horsley, Hewson, Love, Mundry, & Stiles, 2003).

NCLB (2001) set five criteria for PD to be considered high quality. In order to have a confident and durable effect on classroom instruction and teacher performance, PD:

- should be continued, rigorous, and content-focused.
- should directly associate with state academic content standards, student achievement standards, and assessments respectively.
- should develop and increases teachers' knowledge of their subjects' field.
- should furtherance teachers' understanding of effective instructional strategies founded on scientifically based research.
- should be periodically evaluated for impacts on teacher effectiveness and student achievement (Yoon, Duncan, Lee, Scarloss, & Shapley, 2007, p. 1-2).

As cited in Guskey and Yoon (2009), "Effective professional development requires considerable time, and that time must be well organized, carefully structured, purposefully directed, and focused on content or pedagogy or both" (as cited in p.

497). In Turkey, Tataroğlu, Taşdan and Çelik (2014) conducted a research which aimed to introduce a professional development program prototype for eight mathematics teachers and take the participated teachers' opinions about this program prototype. When these opinions were analyzed, it is determined that the purposes and the expectations of the participating teachers are to develop their content knowledge and skills and share their experiences. Another finding of this research was to emphasize the importance of sharing the experiences in their PD; teachers stated that they were pleased with working together and exchange opinions (Tataroğlu, Taşdan & Çelik, 2014).

Guskey and Yoon (2009) drew attention to recent discussions about "best practice" which have influenced PD circles currently. National Staff Development Council (2001) claims that the most effective PD comes from the circumspect combination and adaptation of varied practices rather than applying a particular "best practice" to specific content, process and context elements. Another discussion about PD is related to its content and which contents do improve student learning most. In this regard, the activities which are done in PDs were designed to provide teachers a clear understanding about what they teach and how students obtain this content knowledge and skills (Guskey & Yoon, 2009). Guskey and Yoon (2009) suggest that any new PD action should start with small size and, precisely controlled, pilot studies in order to see whether it is effective or not.

Desimone, Porter, Garet, Yoon and Birman (2002) stated there is a relationship between the intensity and duration of PD and the degree of teacher adjustment. Furthermore, it is important to conceive that PD is a dynamic process which is originated over teachers' life-long experiences and includes diverse learning types (Menezes, 2011). In that sense, teachers should realize that professional development is not a finite process, but a continuous progress.

Although there is a significant amount of literature, there is not exact consensus among researchers on giving the definition of what the effective PD is and in which circumstances they are adequate (İlğan, 2003).

Effect of professional development on teacher quality for mathematics and science teachers

Rapid changes, demands for high standards and calls for developing quality necessitate teachers to update and develop their skills through PD (Craft, 2000). Effective PD engages teachers in learning chances which are encouraging, job-embedded, task-oriented, collaborative, and continuing (Hunzicker, 2010).

School reformers have given significant attention to the role of effective professional development on teachers which may provide great impacts on teachings of mathematics and science teachers (Loucks-Horsley, Stiles, & Hewson, 1996, p. 1). In order to provide a useful framework for giving an idea about the design and plan of PD for mathematics and science teachers; knowledge in the areas of learning, teaching, the nature of mathematics and science, professional development, and how adjustment occurs are taken into consideration (Loucks-Horsley et al., 2003).

Kersaint, Ritzhaupt and Lui (2014) focused on the teachers' use of generic technology (e.g., presentation software, interactive white boards) and content-specific technology (e.g., dynamic geometry software and data collectors) regarding the PD courses of teachers. On the other hand; Loving, Schroeder, Kang, Shimek and Herbert (2007) focused on participant teachers' online professional learning communities (PLCs) which were conducted through blogging and how it affected their use of technology to support their teaching. In both of the studies, the participants were chosen among middle- high school mathematics and science teachers from specified districts of the United States and the studies were conducted under the specified educators' directorships by doing observations and examining the survey data. Regarding the PD and online PLCs, the results have indicated that the participants' use of technology in their teaching practice has increased visibly during the studies. Similarly, both studies seemed to show that if there was an efficient instructional environment for them to learn and practice these technological tools, participant teachers felt more comfortable with using and integrating technology into their teaching practices. Kersaint et al. (2014) suggested that in order to prevent the feeling of frustration on how to use the technological tools in teaching and learning practices, more applications of different technological tools should be introduced to teachers. Likewise, Loving et al. (2007) gave place in their article about the initial uneasiness feelings of teachers on how to use blogging in online PLCs and after the PLC sessions their feelings turned to be positive about blogging.

Loving et al. (2007) stated that the collaboration between mathematics and science teachers via blogging has increased and teachers found blogging as a valuable technological platform that enables to share their resources, ideas and reflect their personal experiences. Kersaint et al. (2014) stated that generic technology was supported by teachers in terms of using in their teaching practices rather than using of content-specific technology. This result led authors to realize that the participants should have been exposed more PD courses related to content-specific technology integration.

Lastly, the study conducted by Desimone et al. (2002) intended to depict a national evaluation of the effects of PD on mathematics and science teachers' instructional development and how their teaching practices has changed by giving the results of three years longitudinal study (1996-1999). The result of this longitudinal study indicated that if the PD spotlights specific teaching practices, it showed an upturn in the implementation of those practices by teachers in their classrooms. Moreover, if teachers participate PD with their colleagues from the same school, department, or teaching the same grade level; effectiveness of the PD showed augmentation.

Researchers in Turkey emphasized the lack of research and studies regarding PD programs and implementations in Turkey (Tataroğlu, Taşdan & Çelik, 2014; İlğan, 2013). İlğan's (2013) research study related to effectiveness of teacher PD gives important information on how PD should implement in Turkey. In the literature, there is a strong consensus on positive effects of PD programs on teachers when the PD activities, presents both content knowledge and teaching methods and techniques, are allocated adequate time and resources, are supported by the school administrators, and provide collaboration among teachers (İlğan, 2013).

Need for a professional learning community in teacher education

Teachers who are deeply committed to their works are classified as good teachers. They have great patience to improve student learning and performance and also increase their self-confidence. This kind of attachment motivates teachers to develop more efficient methods. In that sense "the very essence of a *learning* community is a focus on and a commitment to the learning of each student" (DuFour, DuFour, Eaker, & Many, 2006, p. 3). PLCs provide administrators and teachers work together in the discussion groups, envisaging the class and classroom environment as a community, and improving the classroom experience by sharing with broader community (Hamos et al., 2009). Furthermore, this attachment leads teachers to make cooperative studies with their colleagues beyond the classroom in a wider professional community (Hopkins & Stern, 1996). In a PLC, the term collaboration denotes a process which is systematic and interdependent effort of teachers to affect their classroom practice positively in terms of better improvements for their students, schools, and teams (DuFour et al., 2006).

A PLC consists of collaborative teams in which effort of each team member is interdependent to accomplish their common goals related to intended idea of learning for all (DuFour et al., 2006). Teachers enhance their professional collaborative skills when they have suitable and challenging contexts (Menezes, 2011). In many studies in the U.S., the exchanging ideas and sharing reflection of teachers is becoming an important part of teacher's role in order to improve their practice (as cited in Hopkins & Stern, 1996). Moreover, many high-quality teachers participate in teams to plan and teach together in the classrooms (Hopkins & Stern, 1996). PLC teams involve cooperative inquiry not only in best practices in teaching, but also best practices in learning. They also discuss their current situations in the practices and their students' achievement levels (DuFour, et al., 2006). With making collaboration stronger, the teachers are likely to advance and give a new impulse to their professional identity (Menezes, 2011).

Developing the professional development culture and teaching practices of mathematics and science teachers in the schools requires continuing efforts and encouraging school environment (Oehrtman et al., 2009). The PD designers sometimes face the challenge of combining learning activities with the best meets specific goals and context (Nelson, 2006). Exchange of ideas in teachers' content knowledge for teaching provide teacher to realize and understand student thinking more and make the lesson more meaningful for students (Oehrtman et al., 2009). On the other hand, particular factors such as district, high-stake exams, or school curriculum may cause difficulties for teachers in improving their teaching practice (Oehrtman et al., 2009). It is seen that when there is an executive in PLC sessions who listens the PLC members and discusses with and encourages members in authentic teaching practices, have a positive effect on the quality of the discourse in a PLC (Oehrtman et al., 2009).

STEM education

Science, technology, engineering, and mathematics (STEM) centers upon engagement and skills of students in science, mathematics, and technology from their earliest grades in order to provide constructive and advanced interest in their later school years and consequent careers (Kaszczak, 2013). Instead of acquiring knowledge as fragmentary and practicing it in pieces, STEM provides students an explanation and to interpret the integrated world that we live in (Dugger, 2010). STEM education directs a teaching and learning that include science, technology, engineering, and mathematics disciplines (Bicer et al., 2015). More specifically, Corlu et al (2014) defined STEM education, which integrates skills, knowledge and attitudes specific to each discipline in a coherent way, requires a new approach to teaching and learning mathematics and science. STEM education commonly accepted as an interdisciplinary approach to learning in terms of dealing with real-world problems that are matched to the school context by applying science, technology, engineering, and mathematics disciplines (Tsupros, Kohler, & Hallinen, 2009).

Overview of STEM education: Then and now

The relation between STEM notion's transformation into STEM Education and John Dewey's 'learning by doing' is based on a certain process (Corlu, 2018). John Dewey's institutionalize motto 'learning by doing'- based on instrumentalist learning rather than passive learning- recommends strengthening the bond between school and society (Corlu, 2018). In the 1980s, the federal government and education leaders in the U.S. gradually realized that sustaining 1960s education system in schools would not provide students an enough preparation for the workplace of 21st century (Coleman, 2005). The reports that are published in 1980s such as Science and Engineering Education and Beyond, A Nation at Risk, and The Imperative for Educational Reform also highlighted this issue and set out the following goal "By 1995, the Nation must provide, for all its youth, a level of mathematics, science and technology education that is the finest in the world, without sacrificing the American birthright of personal choice, equity and opportunity" (as cited in Coleman, 2005, p. 1).

The acronym “STEM” was first used in 2001 to attribute science, technology, engineering, and mathematics curriculum by Judith A. Ramaley, who is a former director of the National Science Foundation's (NSF) education and human-resources division, is respected and reputable person by many educators (Teaching Institute for Excellence in STEM, 2010). In 2002, the Math and Science Partnership program of NSF started their research and improvement efforts to strengthen and reform mathematics and science education by STEM disciplinary into K-12 (Hamos et al., 2009). Capraro et al. (2016) stated that; according to the data on NSF and the Institute for Educational Sciences, for the last ten years, presence of STEM education has increased on the national agenda of the U.S.

Conceptual framework for the study

21st century requires each individual to know basic scientific, mathematical, and technological knowledge in terms of its increasing demands on scientific and technological demands (Akaygun & Aslan-Tutak, 2016; as cited in Bicer et al., 2015). STEM education provides required skills for the success in the 21st century (Roberts, 2013b). The inclusive way for effective STEM education is to combine all four disciplines into each other and serve as integrated subject matters in their classrooms (Dugger, 2010).

This study is interested in STEM education which is included in pedagogic STEM. In Turkey, STEM notion has been considered as a pedagogical approach in order to develop the teaching quality (as cited in Aşık et al., 2017). Precisely, integrative STEM education is the main focus of the study. The concept of integrative STEM education is defined by Sanders (2009) as an approach that investigates the relation between/among two or more of the STEM subjects, and/or between a STEM subject and one or more school subjects in teaching and learning. Furthermore, an integrated STEM approach is an active learning and teaching approach that take real-world contexts to explore authentic problems (Hernandez et al., 2014). The study examines the integrated STEM education under pedagogic STEM PD and its reflections on secondary mathematics and science teachers' classroom practices.

STEM education is shaped by the interests and life experiences of students and teachers, and integrates knowledge and skills of main discipline with at least one other STEM discipline (Corlu et al., 2014). Roberts (2013a) states that despite the fact that STEM content is not an innovative approach to education and teachers already adopted and used different STEM subjects in their lessons as instructional strategies, integrated STEM education can make a new difference to education. According to this philosophy, education is not a thing that invests in future; education should be the life itself (Corlu, 2017b).

Patel (2003) suggests that learning and teaching takes place in the holistic approach as "the social process of allowing critical learners to claim ownership of the knowledge domain, its epistemology, and to make knowledge refutations or claims based on that, such that it enables action in real situations" (p. 274). The approach has been developed and implemented in teaching in order to provide a motivation and significant learning for learners (Patel, 2003). In this approach, both teachers and students provide configurations of the learning and knowledge respectively (Corlu, 2017b). During the configuration process, teaching profession is developed from external sources, personal experiences and cultures, building relationships with students based on their learning styles and even from the students' knowledge (Corlu, 2017b).

The conceptual framework of this study called as STEM: Integrated Teaching Framework (InTeachFramework; See Figure 1 which aims to combine the holistic approach and integrative STEM education. InTeachFramework, under the holistic movement is affected from process philosophy (Corlu, 2017b).

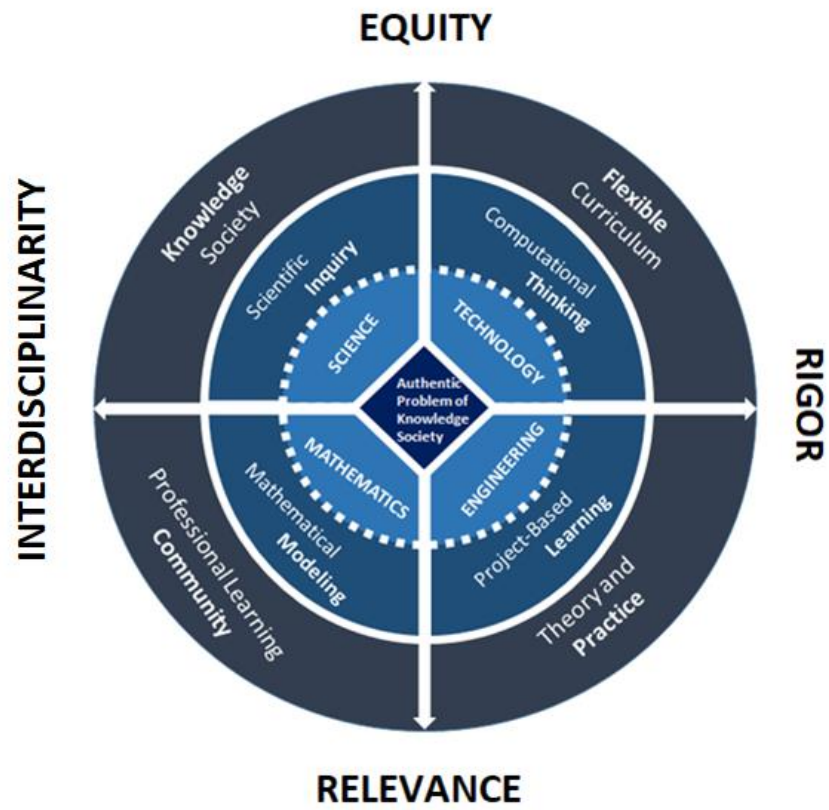

Figure 1. STEM: Integrated Teaching Framework. Reprinted [or adapted] from *STEM Kuram ve Uygulamaları* (3), by M. S. Corlu, 2017b, Istanbul: Pusula.

InTeachFramework is assembled on four domains: principles, social products, cognitive processes, and scope and sequences (Aşık, Doğança Küçük, Helvaci, & Corlu, 2017). The first domain consists of principles which are equity, relevance, interdisciplinarity, and rigor in main discipline should be seen as teachers' selfregulation tool in their implementations (Corlu, 2018). Social products constitute the second domain which is listed as knowledge society, professional learning community in school and beyond, flexible curriculum in classroom, and theory and practice. Third domain refers to the cognitive processes of Integrated Teaching. This domain is shaped from scientific inquiry, project-based learning, computational thinking, and mathematical modeling. Computational sciences can be defined as developing mathematical models for complex and dynamic problems of the twenty-first century by stimulating on the computer (Corlu, 2017a). Fourth domain includes scope and sequence of integrated teaching that are STEM disciplines in the curriculum. In the core of the framework the holistic movement is placed namely as Authentic Problem of Knowledge Society (APoKS). According to holistic approach that emerges from APoKS, knowledge is affected by not only external world but also subjectivity of time, place and individuals because the connections and relations are more important than the knowledge itself (Corlu, 2017b). In that sense, dynamic and complex structure of multiple variables of 21st century should be examined under with well-defined problems that include limitations and do not direct students to a single predetermined correct solution (Corlu, 2017b).

InTeachFramework, Corlu (2017b) listed teachers' overall targets as below:

- Without restricting just in school ecosystem, teachers make contributions to society in order them to become a knowledge society,
- As part of PLC, teachers place the learning culture into their schools,
- Teachers contribute to integrity of theory *and practice*; by attributing their actions to research results from the body of literature, performing their own actions if required, or by collaborating with researcher,
- Teachers develop dynamic and open to changings flexible curriculums to their schools (p. 4).

The fundamental principles that provide balance to teachers regarding their above aimed actions:

- Equity – Relevance: Caring about every student's relevance and life experience,
- Interdisciplinarity –Rigor: Without neglecting the main discipline's target knowledge and skills, planning interdisciplinary implementations during the lessons (Corlu, 2017, p. 4).

The role of professional development in STEM education

It is important to conceive that when in-service teachers attend to PD activities, they are already skilled and qualified adults in education field (İlğan, 2013). Hunzicker (2010) adverts to adult learners and their learning styles which play an important role in designing, implementing and evaluating a PD program for in-service teachers. Especially as groups, Knowles (1983) states that adult learners are self-directed, eager to learn, task-oriented, and motivated from their nature (as cited in Hunzicker, 2010). Specifically; adults prefer open-ended learning chances and incremental progress in their learning. They improve their learning by setting clear goals and link their life experiences with new information in order to make sense and produce solutions (Hunzicker, 2010).

It is important to consider that STEM education contains not only mathematics and science, but also technology and engineering principles that are the necessary skills for the future jobs (Roberts, 2013b). To help students get prepared for 21st century workforce in their jobs, schools are starting to assess their education system and scrutinize strategies which provide an increase in the quality of STEM education overall (Capraro et al., 2016). Within this context, mathematics and science teachers started to use real-life applications with including appropriate latest technologies into their classrooms from many countries (Akaygun & Aslan-Tutak, 2016). PD can offer opportunities for those who involved in the teaching of STEM to learn how to effectively integrate various instructional approaches, including engineering design into their teaching and learning environments. Regarding Hunzicker's (2010) in-service teacher learner profile and the general aim of STEM education, holistic approach to learning and teaching is the main desideratum from teachers to obtain after the STEM PD program.

According to research, the STEM PDs mostly concentrate on mathematics and science disciplines and it is generally concluded that there are effective engagements of mathematics and science teachers in these PDs (as cited in McDonald, 2016). Furthermore, PD related to technology and engineering specifically help teachers develop their PCK on technology and promote how to apply design-based learning approached in their classrooms (as cited in McDonald, 2016).

Long-term PD can promote STEM reform. Capraro et al. (2016) presented effective results to make connections and comparisons with the current PD courses which take place in Turkey. It mainly focused on the impact of long-duration PD on the quality of classroom implementation of the STEM-oriented PBLs by examining unprocessed scores of students on the state's high-stake test in mathematics, science, and reading. Apart from this, in order to collect qualitative data; teacher observations and focus group interviews with teachers and administrators were considered. In the study, the researchers claimed that particularly effective research-based STEM PD on project – based learning (PBL) and PLCs provided recognizable student learning gains regarding the high-stake exam scores. Furthermore, it was highlighted that if the school administration supported teachers about PLCs, teachers' behaviors in classroom and their application on the STEM PBLs showed improvement which was directly affected student learning positively (Capraro et al., 2016).

Considering the education system in Turkey, the actions that teachers follow related to PD programs should be systematically organized and embedded into their jobs to make teachers active during the school time and in the school area (İlğan, 2013). Therefore, in order to have effective STEM implemented lessons in-service teachers need to experience quality STEM activities and develop some related activities themselves with the support of trainings (Akaygun & Aslan-Tutak, 2016).

CHAPTER 3: METHOD

Introduction

This chapter presents the methodology of the study. It starts with explaining the focus of research design, and then continues to specify context, participants, and instruments. Finally, methods of data collection and analysis procedures are described.

This study addresses the following research questions:

1. How can this initial STEM PD program be described?
2. How does initial STEM PD affect the classroom practices of mathematics and science teachers?
3. What are the indicators that affect mathematics and science teachers' teaching philosophy according to their perception after taking the initial STEM PD program?

Research design

This study is qualitative in nature and designed under exploratory case study research (Yin, 2003, p. 5). "An exploratory case study aims at defining the questions and hypotheses of a subsequent study or at determining the feasibility of the desired research procedures" (Laws & McLeod, 2004, p. 5). Gay, Mills and Airasan (2008) highlight that case studies are applicable to describe the context of the study and implement a specific program or innovation which continues for a specific period of time. This study is centered on an initial STEM PD program that was conducted to particular secondary science and mathematics teachers. Furthermore, the phenomenon which is influenced by its context should be also taken into the consideration by the researcher while answering the research questions (Baxter & Jack, 2008). In order to determine the science and mathematics teachers' classroom practices and teaching philosophy, the initial STEM PD program for this study was considered under its context. Unit of this study is the initial STEM PD program and the products are the teachers' classroom practices and developments on teaching philosophies.

Context

Gay, Mills and Airasan (2008) defined case study research as "… a qualitative research approach in which researchers focus on a unit of study known as a bounded system (e.g., individual teachers, a classroom, or a school)" (p. 426). The current study took place at a private K-12 school which is in a metropolitan city in Turkey. The school has a big campus that provides many environmental and social opportunities including activities for their teachers and students. The school is recognized nationally for its high academic achievement in the national high-stakes exams. The students are admitted to the school after an entrance exam for each grade level. In the secondary education of this school, both MoNE and International Baccalaureate (IB) Diploma Program (DP) curricula are implemented. In secondary school, the divisions of classes are not homogeneous but ability grouping is used. For each grade level, there are three different types of classes which are Anatolian classes, science classes and IB DP classes. In the school web-site, it is stated that course load for students in the secondary education is more intense than the requirement of MoNE curricula for all their classes. In that sense, Anatolian classes are following MoNE curriculum. Science classes are following not only MoNE curriculum but also advanced topics within curriculum. IB DP classes focus on International Baccalaureate program apart from MoNE requirements.

STEM professional development process

Under the supervision of a teacher education professor with a doctoral degree on STEM education, STEM PD program were conducted in the high school building of this school campus. PD agenda was shaped with administrators of the school and PD facilitator according to the needs of teachers beforehand. All seminars, workshops and PLC meetings followed STEM: InTeach Framework (Corlu, 2012; 2017b). From September 2015 to March 2016, the STEM PD seminars-workshops and PLC meetings took place on Friday and Saturday consecutively in every month except January and February. PD was not conducted on January and February because it was the break time of the education year. From September to March, seminars-workshops started at around 13:30 and ended at 16:30. Although it was mandatory for the participants to attend the PD courses, attendance for the PLC meetings was optional.

Participants

The sample was purposefully selected (Fraenkel & Wallen, 2006, p. 99). Participants of this STEM PD seminars-workshops and PLC meetings consisted of 27 secondary mathematics and science teachers of a private high school. Ten of them were mathematics, six of them were physics, six of them were chemistry and five of them were biology teachers. Regarding the gender of the teachers; 18 of them were male and nine of them were female. All teachers teach in every grade and level at high school including Anatolian, science, and IB DP classes.

Instrumentation

To explore the initial PD program, mathematics and science teachers' level and quality of collaborations, both voice records and observation forms of STEM PD seminars-workshops and STEM PLC meetings were taken into consideration. Apart from STEM PD seminar-workshop and STEM PLC meeting observation forms and voice recordings, lesson observation forms, group workshop research-record books were used for data collection.

Observation forms

There are three types of observation forms used for this study. One is designed for PD seminars-workshops, the other one is designed for PLC meetings, and one for the classroom practices of the teachers.

PD seminar- workshop observation form

The PD seminar-workshop observation form consists of three main parts: before seminar-workshop, during seminar-workshop, and after seminar-workshop observation respectively. Before seminar-workshop part comprises STEM PD team's rehearsal notes related to seminar and workshop preparation. During seminar part is divided into four columns;

1. Time
2. Memos outline the STEM PD team's discourses and guidance

3. Detailed notes related to participant teachers' actions, reactions and performances
4. The emphasis on STEM focal point of the month

Ultimately, after seminar-workshop part gives post-seminar and post-workshops remarks of STEM PD team. The PD seminar-workshop observation form template can be seen in Appendix A. All PD seminar-workshop forms were filled in by the researcher.

Professional learning community meeting observation form

PLC observation form has three items; the list of the teachers' names who attend, discussed/issued topics, and results-discussions at the end of the meeting. Using the information provided by participants the researcher could examine whether teachers exchange of their ideas about STEM activities and how they implement these ideas into their lessons by collaborating each other during STEM PLC meetings (Appendix B).

Classroom practice form

The form of classroom practices has three parts; information about pre-lesson planning, lesson observation and post-lesson interview notes (See Appendix C). The first part, pre-lesson planning includes the process of arrangement of the chosen lesson observation date with teachers. Second part of the form includes the observation of whole lesson which consist of forty minutes. This part divided into four columns; time, teaching, learning, and STEM focus of the month. Last part comprises acknowledgement, summarization of observation notes, and reminding teachers related to their lessons. The observation forms for classroom practices were filled in by teacher educator and the PD team members.

Voice recordings

PD seminar-workshop and PLC meetings' voice records were taken by the researcher during the sessions. Lesson observation voice records were taken by the facilitator and other member. It helped researcher not to miss any important conversation related to research questions.

Workshop research-record book

The research-record book is for teachers to discuss and plan their tasks during the workshops. The booklet helps teachers to work on a task and prepare a product that follow the STEM: InTeachFramework. To some degree, it was a rubric for the workshop products that were expected by teachers to prepare with their groups at the end of each workshop (See Appendix E). It provided researcher to evaluate workshop performances and collaborations of teachers during workshops.

Teachers' reflections

In order to examine teachers' perceptions about how they develop their teaching philosophies, they wrote 800-1000 words reflection about their experiences within the whole process of STEM PD program.

STEM lesson plan preparation guide

STEM lesson plan contains five main parts (See Appendix D). The first part is related with goal and objectives of the lesson which should include main discipline objectives, other STEM discipline objectives, and social product objective. The materials and sources used are composed of second and third parts respectively. Fourth part is related to detailed explanation of APoKS with indicating its limitations. Last part is used for writing the content of the lesson which is designed based on the 5E model comprises engage, explore, explain, extend, and evaluate titles respectively. 5E model, developed in 1987 by the Biological Science Curriculum Study, encourages collaborative and active learning in the lessons ("Empowering Students: The 5E Model Explained", n.d.).

Method of data collection

Before the data collection process, a proposal was prepared and requested permission from the MoNE by PD facilitator to administer the instrument with his team. In-depth exploratory data was collected as follows:

Table 2
STEM PD program data collection

Date	**Module: STEM focus topic of the month**	**Data**
September, 2015	Module 1: Interdisciplinarity	Workshop Data: Seven research-record books
September, 2015	Module 1: Interdisciplinarity	PLC Data: voice record, observation form
October, 2015	Module 2: Rigor in Main Discipline	Seminar Data: voice record, observation form Workshop Data: voice record, observation form, five research-record books
October 2015	Module 2: Rigor in Main Discipline	PLC Data: voice record, observation form
November, 2015	Module 3: Relevance to Authentic Problems of Knowledge Society	Seminar Data: voice record, observation form Workshop Data: voice record, observation form, five research-record books
November, 2015	Module 3: Relevance to Authentic Problems of Knowledge Society	PLC Data: voice record, observation form
December, 2015	Module 4: Assessment	Seminar Data: voice record, observation form Workshop Data: voice record, observation form

Table 2 (cont'd)
STEM PD program data collection

March, 2016	Module 5: Discourse -Argumentation	Seminar Data: observation form, reflection papers
April, 2016	Classroom Observations	Data: observation forms, voice records, STEM lesson plans

STEM professional development seminars -workshops

STEM focus topics were introduced in each initial STEM PD seminar by STEM PD team. After the seminars, teachers were obliged to make groups with their colleagues in order to do STEM PD workshops related to given specific APoKS. During the first seminar definition of APoKS were introduced to teachers and every workshop teachers were trying to find solution offers for different APoKS in groups. The group members consisted of different subject areas. During the workshops, groups were expected to complete the given workshop research-record books with generating workshop products. In each group, every member should have a different role related to given task. Teachers may have changed their groups in every PD workshop.

Professional learning community meetings

PLC meetings were done during the first three modules (See Table 2) that were organized with teachers. Teachers were expected to share their ideas and prepared lesson plans related to STEM topic of the month that was given a week before on the PD seminars. Also, collaboration ideas with or/and within subject groups were discussed with STEM facilitator in detailed. Ten teachers (4 mathematics teachers, 5 physics teachers, and 1 biology teacher) at the first and second PLC meetings and 6 teachers (5 mathematics teachers, and 1 biology teacher) at the third PLC meeting were contributed.

Teachers' reflections

On March, 2016, the last seminar day, teachers wrote reflections about what kind of improvements they observed about themselves and how they understood they improved during this initial STEM PD process. There are seventeen reflections that are written by teachers who attended this STEM PD.

Classroom practices of teachers

Finally, classroom practices of teachers were observed in April, one month after the end of STEM PD. Teachers were contacted two days before the observation day. From 27 secondary mathematics and science teachers, ten teachers' classroom practices were examined by looking at their lesson observations. These ten lessons included four physics teachers (will be named as physic teacher 1, physic teacher 2, physic teacher 3, and physic teacher 4), three chemistry teachers (chemistry teacher 1, chemistry teacher 2, and chemistry teacher 3), one biology teacher and two mathematics teachers (mathematics teacher 1 and mathematics teacher 2). One month after the last STEM PD seminar-workshop, classroom practices of teachers were observed by seminar facilitator and the member from STEM PD team. Researcher enumerated teachers spontaneously. Before commencing STEM PD seminar-workshop and PLC meeting, those teachers' classroom practices were not observed. The duration of the lesson observation was one lesson period, 40 minutes. The rubric for classroom observation was shared with teachers beforehand, at the end of the last PD seminar-workshop. Observations were done in the classroom environment with the students in their usual classes.

Methods of data analysis

The data for this study was gathered from an initial STEM PD process that was implemented on 27 science and mathematics teachers from a range of secondary grade levels. Qualitative data was gathered from observation forms, voice records, research-record books, reflections and STEM lesson plans. Regarding the data processing and preparation, the researcher used qualitative content analysis method. Content analysis is for analyzing written, verbal or visual communication messages (as cited in Elo & Kyngäs, 2008). Researcher used deductive content analysis which is applicable for testing categories and/or concepts in a new context. Connections, comparisons and relations among the collected data were analyzed under the categorized titles that are named “focal points”. These focal points were interdisciplinarity, rigor, relevance, and equity. The categorization was done according to the conceptual framework of this study which is STEM: InTeachFramework.

For the first research question, data acquired from PD seminar, PD workshop and PLC meetings. Each module of the initial STEM PD program was designed according to the principles of STEM: InTeachFramework, which are also the focal points of this study. After the initial screening of this data, each data from STEM PD program’s modules provided the researcher with a list of indicators. These indicators helped the researcher have a better in-depth understanding of the data. Deductive content analysis facilitated to distill indicators into fewer categories and to code the data according to these categories (Elo & Kyngäs, 2008, p. 111). From the information that was acquired from research question one, the following research questions analyzed according to focal points and their indicators but with different analysis methods apart from content analysis which is a flexible research method that can be used with other methods in information studies (White & Marsh, 2006). Other analysis methods were explained in the following paragraphs.

Second research question, which is related to teachers' classroom practices, was analyzed by adopting interpretivism, since it highlights the ability of an individual to build meaning (Creswell, 2007; Mack, 2010). Interpretivism can be explained as qualitative approach that researcher interprets the data with a subjective perspective (Creswell, 2007). In this study, the researcher analyzed classroom practices of teachers by analyzing mainly observation forms of classroom practices which were fulfilled by STEM PD team. Firstly, data analyses were done under the title of each focal point considering how each focal point and their indicators referred in the lesson plans (if prepared), in-class activities, instructive worksheets (if prepared), activity sheets (if prepared), and discussions during the lessons respectively. Secondly, under the approaches to authentic problems of knowledge society (APoKS), the researcher analyzed whether classroom practices were done based on a specific real-life problem and reflected STEM integrity as a whole.

For the third research question, the researcher used process and in vivo coding methods in analyzing the collected written and voice record data from STEM PD. The process coding method provides expressing observable action in the data that culls participants' interaction and consequences (Miles et al., 2013). Original language of participants' words and short phrases in the data record are used as codes (Miles et al., 2013). In the current study, the written observational data acquired from PD seminars-workshops and PLC sessions were transcribed and coded under related focal points regarding process coding method. Researcher considered the participants' reflections, research-record books and their group conversations which were placed in the voice record of PD workshop/seminars and PLC meetings are transcribed and coded under in vivo coding method.

Trustworthiness

According to Lincoln and Guba (1985) trustworthiness should be established on four domains; credibility, transferability, dependability, and conformability. In order for establishing credibility and trustworthiness, researcher used prolonged engagement, persistent observation, peer-examination, and triangulation techniques as shown in Figure 2.

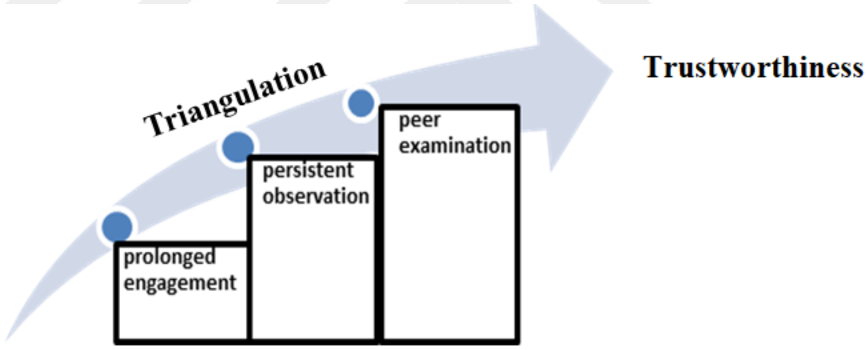

Figure 2. Elements of Trustworthiness

First of all, researcher attended all STEM PD seminars-workshops and PLC sessions by taking observation notes (See Appendices A and B for observation forms) during the whole process of PD program. During this eight-month long process fulfilled researcher's need on spending prolonged time in the field to acquire and develop an in-depth understanding of the culture and phenomenon (Cohen & Crabtree, 2006). The detailed explanation of the flow of the PD seminars-workshops and PLC sessions were noted in the observation forms. Furthermore, researcher applied persistent observation technique in order to detect and assess salient factors and critical exceptional happenings (Lincoln & Guba, 1985). Researcher added environmental impacts and teachers' reactions, movements, and interactions to each other on the observation notes. All written observation notes were valuable for connecting the teachers to the experiences and analyzing the context.

In order to contribute to the trustworthiness of findings, peer examination technique was used (Merriam, 1995, p. 56). As Lincoln and Guba (1985) stated peer-examiner needed to be experienced in methodological issues. In this consideration the chosen peer was someone who has experiences in qualitative research and teacher education and not from the research team. He examined the data and analyzed the collected data to contribute the validity of data collection and analysis (Gibson & Brown, 2009).

Lastly, methodological triangulation technique was used by applying more than one kind of method to study a phenomenon (Bekhet & Zauszniewski, 2012). In that sense, researcher used multiple data collection methods in order to ensure triangulation of the data (Merriam, 1995, p. 56). Apart from lesson observation forms and reflections of teachers, STEM PD seminar-workshop' and PLC meetings' observation forms, research-record books of teachers and finally voice records of STEM PD and PLC provide researcher more comprehensive data. With this comprehensive data the validity of the data improved and researcher's understanding on phenomenon has increased. Moreover, as Denzin (1970) and Mathison (1988) mentioned triangulation helped researcher to confirm the initial findings with the multiple sources of data (as cited in Merriam, 1995).

In addition to trustworthiness, the confidentiality of the participants and STEM team was ensured. In the beginning of STEM PD program, facilitator introduced researcher to participants and explained the purpose of being there. Researcher informed and asked permission about the data collection instruments that were stated detailed above.

CHAPTER 4: RESULTS

Introduction

This chapter presents the findings of the data analysis that were gathered from observation forms, voice recordings, research-record books, classroom practices and reflections.

Findings of the study

In this section, the findings were given under three main parts that were organized according to the research questions. First part includes the description of the initial STEM PD program and its way of implementation. Second part presents the findings related to the contribution of STEM PD to the classroom practices of teachers. Finally, the third part focuses on the contribution of STEM PD to the teaching philosophy of secondary mathematics and science teachers according to their perception.

For the first part PD seminar and workshop, workshop research-record books, PLC meeting observations, and all of their monthly voice records provided researcher valid data about what teachers acquired and practiced during this initial STEM PD. In the second part, results were obtained from classroom observation forms, teaching materials (activity sheets, lesson plans, etc.) and voice records of the observed lessons. In the third part, results were obtained mainly from teachers' reflections that were written by teachers in their last STEM PD seminar.

Description of the initial STEM PD program

Detailed PD context for seminars and workshops is provided in the Table 3.

Table 3
PD seminar-workshop

Modules	STEM focus topic of the month	Tasks - Workshops	Actions for APoKS
Module 1	Interdisciplinarity	Hydrogeology Engineering (Chemistry)	Teachers prepared specific solutions as if they were hydrogeology engineers by using their chemistry, physics, and mathematics knowledge.
Module 2	Rigor in main discipline	Plane Construction (Physics)	In groups, teachers constructed planes with the given limited materials.
Module 3	Relevance to authentic problems of knowledge society	Solar Energy School Construction (Mathematics)	Teachers designed their new science high school building by investigating solar energy building and calculating mathematical equations. Then they constructed their buildings with the given limited materials in groups.
Module 4	Evaluation, measurement, and assessment	Lesson Plan Evaluation with Peers	Teachers evaluated the given sample STEM lesson plans in peers which are prepared by other teachers from other schools. Then altogether peers discussed how they assessed the lesson plans.
Module 5	Discourse - Argumentation		It was asked for teachers to write an essay about their experiences during the process of the PD and how they felt.

In the first seminar, PD agenda and the first STEM focus topic of the month were introduced. For the following four seminars, previous STEM focus topics reviewed and discussed with the teachers. Possible project and collaboration ideas, which were discussed with teachers in the last PLC meetings, were shared. Then the current STEM focus topic was introduced.

During the PLC meetings, facilitator and attended teachers were sitting around the meeting table. They exchanged opinions on and did brainstorming about the possible STEM projects. Facilitator carried out discussions one-on-one and/or together with teachers. Also, teachers discussed possible collaboration ideas with each other at that time, and after they consulted their ideas with facilitator.

At the end of each PD seminar-workshop and PLC meeting, STEM PD team did a short evaluation of the actions, discussions, and argumentations that happened on that day.

Regarding the context of PD program, general description related to PD program is as follows:

Module 1 –Interdisciplinarity

Seminar: The first seminar included discussions related to benefits of interdisciplinarity in teaching. PD team introduced APoKS with giving the baseline definition. Then together with teachers they discussed about two main properties of APoKS; other discipline should be included and has more than one solution. While the discussions were continuing from the given possible APoKS examples, PD team remarked on the difference between APoKS and real-life problem is other disciplines are involved in APoKS.

Workshop: Although the main discipline was chemistry, the PD integrates physics, mathematics, and engineering learning objectives too. There were 7 groups and 6 of them found possible desired solution plans for the given APoKS and the solutions were different from each other. According to their solution plans, they prepared specific solutions as if they were hydrogeology engineers by using their chemistry, physics, and mathematics knowledge.

PLC meeting: Facilitator and attended teachers discussed six interdisciplinary project ideas for APoKS. One of the interdisciplinary ideas of a biology teacher was related to use of enzymes in biotechnology which may provide an integration of biology with engineering and chemistry. For providing computational thinking in STEM practices in the lessons a physics teacher consulted facilitator about teaching Breadboard to students.

Module 2 –Rigor in main discipline

Seminar: "What does rigor refer in teaching?" and "How can an effective rigor in main discipline be provided in the classrooms?" questions were the focus of the seminar. In order to contribute the importance of rigor's meaning in teaching, PD team presented five effective rigor examples. Such as in the project of GoogleX elevator that will connect the Earth and the Moon, teachers were asked to express the distance mathematically in terms of the thickness of the different substances to be used. Here PD team requested teachers to make this elevator from one piece of paper and present it under limitation title. Also the rest of the presented rigor examples included limitations that led teacher to deepen their knowledge while discussing them.

The importance of limitation in APoKS was given as the key element that link the problem to the objectives set by the teacher. Teachers individually or in groups tried to find the possible solutions for each example.

Workshop: After giving the STEM disciplines' learning objectives that are physics and engineering, 5 groups made possible solution plans for the given APoKS. Then, in group, teachers constructed planes with the given limited materials and tried whether they can fly or not. For rigor part of APoKS, one of the extended questions was "How does one measure the distance a car, a ship, and a plane take?" The other one was an advanced research question which was finding the relations between the speed of the plane and Pitot tube. The questions were gained attention by groups and teachers discussed the possible answers with relevance.

After seminar and workshop, STEM PD team raised concern about the time of the seminar part. There was not enough time for discussing the focus topic of the month clearly with teachers. Likewise, during the workshop, generating products of the desired solution for APoKS took so much time, but eventually team decided to continue this product making process.

PLC meeting: Thirteen STEM project ideas were discussed during the meeting comprehensively. After teachers shared their interdisciplinary project ideas, all together, they discussed what can be the rigor part of this STEM project under the moderation of facilitator. For example, one physics teacher presented a STEM project that includes physics and engineering disciplines. For the topics optic and electricity, firstly teacher asked students to explain the transmission of electricity from hydroelectricity and nuclear power stations. Then he wanted students to generate electricity by using solar energy and optic. Facilitator contributed this idea with sharing an APoKS idea which is students could produce a non-stop running solar panel by plugging a motor. Furthermore one mathematics teacher was involved to discussions and added that this project is also related with mathematics. Students can form parabolic and hyperbolic equations when it was asked them to show the warming water with solar panels. Finally facilitator suggested that for rigor part they could ask students to work on a project that produce energy by using solar energy and mirrors.

Module 3–Relevance to authentic problems of knowledge society

Seminar: PD team started the seminar by doing a short summary of what they have been done in the last couple of months. Firstly, they implied the importance of interdisciplinarity; facilitator likened interdisciplinarity among science subject groups to the relationship between the branches of medicine and disease. When there is a disease, a lot of specialists needed to examine for diagnosis. Just like in science lessons; in order to make it clearer for students, it should be taught in separate lessons (physics, chemistry, and biology) but it should be considered as whole under the roof of science discipline. Every teacher shared their ideas on integration of STEM disciplines into their subject groups. Teacher stated that use of technology in school is limited, especially in mathematics preparing students to national exams outweighed.

Secondly, PD team suggested some academic books and web-sites for teachers, when they were preparing rigor part for their STEM practices. Since the school is an IB DP school, facilitator suggested IB program's online curriculum center web-site. Teachers were hesitant about applying rigor in main discipline in their lessons. They stated that sometimes these rigor questions may have confused some students about the topic.

Finally, PD team introduced relevance focus topic. Under the title of math in movies, they showed some movies related to mathematics and discussed with teachers about the movies' contents and how the mathematics is visible at the theme of the movie.

Workshop: PD team presented a problem that was stated by the school administrator related to their new school building. They were planning to make windows on the south side from photovoltaic glasses that produce solar energy, but they had some difficulties in applying this idea and changed their mind. Considering this problem, before giving APoKS, PD team wanted groups to do preliminary investigation about the following three questions:

- What are the properties of eco-friendly buildings?
- What is the difference between passive and active solar buildings?
- What is photovoltaic glass?

Teachers, who were assigned as researchers in group, started to investigate above questions from their mobile phones and took notes on their research-record books. Then PD team presented APoKS with its limitations. Teachers designed their new school building by investigating solar building and calculating mathematical equations to generate a general volume formula for their building. Here, the main discipline was mathematics; engineering discipline was integrated under this APoKS. Finally, groups constructed their buildings with the given limited materials in groups.

PLC Meeting: Mathematics teacher stated that they were planning to implement solar energy school STEM project, which they have done in the last workshop, to the grade 9 students. By using Desmos program, students could construct sample school buildings over equations with regard to use of solar energy.

Module 4–Assessment

Seminar -Workshop: After STEM PD team distributed STEM lesson plan samples; they created a discussion environment for writing target acquisition in STEM education. During the discussion, facilitator emphasized on how to write engineering and technology learning objectives in the lesson plans. Then, teachers examined rubric samples by discussing with their groups. Lastly, PD team played Kahoot game with the teachers. Teachers showed interest on Kahoot. At the end of the seminar, teachers shared their ideas on STEM lesson plan samples and rubrics of APoKS. Facilitator asked a question: “What is the role of teacher in STEM education?” Teachers’ answers were generally implied that the person who guides students in every aspect of the lesson. On the other hand, STEM PD facilitator highlighted that in STEM education, teacher is the person who design the lesson entirely.

Module 5–Discourse-Argumentation

Seminar: In the last month of the STEM PD, facilitator emphasized some points related to improve discourse and argumentation in the classroom environment:

- Calling students to the chalkboard to express themselves.

- Not choosing random students for discussions or in making in groups.
- Repeating students' answers.
- Asking questions start with "What if …"
- Asking questions with no answers.

He also stated that STEM practices should be done in the normal course flow, students should not feel that these practices are more like activities than lessons. STEM focus topics of the STEM PD program which are interdisciplinarity, rigor, relevance, assessment, and discourse-argumentation were formed based on InTeachFramework. In Table 4 below, indicators of STEM focus topics that were emphasized by STEM PD team during STEM PD workshop/seminars and PLC meetings are listed.

Table 4
Indicators of focus topics

Interdisciplinarity	Rigor	Relevance	Assessment	Discourse - argumentation
•science •mathematics •engineering •technology •main discipline •main discipline and connections of other disciplines •collaboration with other subject groups •integrating other disciplines	•interdisciplinarity •extended questions •limitations •deep approach to learning •flexible curriculum •connection with prior knowledge •advanced research •scientific inquiry •computational thinking •mathematical modeling •balance of theory and practice	•interdisciplinarity •rigor in main discipline •preliminary – sustained investigation •real-life applications •more than one solution •caring life experiences and needs •eco-friendly •material needs •online sources •social media-news •emphasis on main discipline	•rubric preparation •target acquisition/ objective/goal •emphasizing on interdisciplinarity and engineering •formative assessments •summative assessments •interactive assessments •differentiated assessment tools •self-assessment •peer-assessment •feedback on students work	•student-centered •relevancy on the topic/subject •pair/group activity •open –ended exploration •starting an argumentation in the class •effective monitoring tools •efficient use of time •enhancing & sustaining the collective participation

Indicators were designated by researcher according to frequency of use by STEM PD team during STEM PD seminars -workshop, PLC meetings. Researcher preferred not to state APoKS as an indicator, because all STEM focus topics comprised of APoKS. Also, there is no hierarchical order among indicators. As it can be seen in Table 4, first three STEM focus topics are associated to each other inclusively. Concerning their pedagogical indicators, assessment and discourse-argumentation STEM focus topics are interrelated and can be displayed as bindings of the first three STEM focus topics that emphasized pedagogical STEM. In that sense, assessment and discourse-argumentation STEM focus topics assembled under the same roof as equity which is a principle of InTeachFramework.

Based on the conceptual framework for the study, four "focal points" were identified within the baseline definition. These focal points are interdisciplinarity, rigor, relevance, and equity. Below table (Table 5) displayed the classification of indicators that were sharing the same meanings, words, and phrases under the focal points.

Table 5
Distillation of indicators under the focal points

Interdisciplinarity	Rigor	Relevance	Equity
• STEM disciplines • main discipline and connections of other disciplines • collaborations	• interdisciplinarity • limitations • deep approach to learning • advanced research • connects to higher education level • extended question	• interdisciplinarity • rigor in main discipline • real-life applications • caring life experiences • more than one solution • eco friendly	• assessment • argumentation and discourse • lesson plan preparation • use of time • differentiated instruction tools • monitoring tools

Findings related to the contribution of PD based on STEM to the classroom practices of secondary mathematics and science teachers.

Ten teachers' lessons were observed by facilitator and another member from STEM PD. The results only focused on the implementation of indicators of each focal point in the classroom practices within an APoKS baseline. In this context, classroom practices of chemistry teacher 2 were excluded from the findings since she did not include any indicator of first three focal points clearly. Only indicators of equity were included such as group work but could not be analyzed as a STEM lesson. The findings related to classroom practices of teachers were given separately under each focal point.

Interdisciplinarity

Herein, researcher focused on how indicators' of interdisciplinarity were used in classroom practices of teachers. Science, mathematics, engineering and technology indicators are the STEM disciplines that are needed to be treated as concentric in intended STEM lessons. At the same time, main discipline indicator should always be visible in STEM lesson. Main discipline and connections of other disciplines, and collaboration with other subject groups are the important indicators in order for creating APoKS.

In observed lessons, teachers generally planned their lessons as main discipline-centered and integrated other STEM disciplines into their activities or discussions. In total, six teachers made interdisciplinarity observable in their classroom practices. Additionally, science teachers' classroom practices embraced the indicators of interdisciplinarity more than mathematics teachers' classroom practices.

During the STEM PD seminar of module 3, facilitator associated interdisciplinarity among science subject groups to the relationship between the branches of medicine and disease. In this regard, these six science lessons ably reflected that above analogy. Apart from mathematics indicator, science indicator was also placed in their lessons and main discipline and connections of other disciplines. Among science teachers, all physics teachers used interdisciplinary approaches in their classroom practices. Specifically; one chemistry teacher, four physics teachers, and one biology teacher used interdisciplinarity in their lessons. In the following lessons, apart from mathematics and science, technology and/or engineering indicators were seen as STEM objectives in the lessons.

Physics teacher 1 emphasized collaboration with a chemistry teacher, in order to relate Heat and Temperature with generated heat from the chemical reaction. Teacher also connected this relation with technology and stated as a learning outcome.

In the other physics lesson, physics teacher 2 derived benefits from biology, mathematics and engineering subjects as interdisciplinary applications. The topic was Fluids and Bernoulli Principle, which was also the topic of workshop task in Module 2: Rigor in Main Discipline. During the workshop, the learning outcomes were given as engineering and physics. In this lesson learning outcomes belong to physics and application of Bernoulli principle in daily life. In addition teacher did an interdisciplinary activity by asking students to draw speed-pressure graph of these different ball types which provided integration with mathematics discipline.

Finally, physics teacher 3 wanted students to use their technology and engineering knowledge while designing an electricity motor under the topic of Electricity and Motion Energy. On the other hand, he included only physics learning outcomes as STEM objectives into his lesson plan. Including engineering outcomes may have assisted students during the design of electricity motors.

Below lesson plans practiced interdisciplinarity principle without giving any goals-objectives to students, but provided effective mathematics and science indicators and their connections with the main discipline.

In the lesson of chemistry teacher 1; the topic, Wave Model of Electromagnetic Radiation was associated with bow wave and wavelength of light in physics discipline during the whole lesson. Towards the end of the discourse of students about the connection of two topics was kind of a proof of interdisciplinary approach of the lesson.

Physics teacher 4, in the topic Density, Mass and Volume, he used mathematics and chemistry disciplines in the calculations, and biology discipline in the discussions to relate mass with motions of the lakes.

Biology teacher did a STEM lesson under the topic of Bacteria and related this topic with mathematics. Students calculated the zone of inhibition by calculating the area of a drawn agar plate on the instruction sheet. Secondly, students drew the graph of given data related to the effects of antibiotics in years.

In order to be able to talk about interdisciplinarity, the disciplines must be clearly visible (Corlu, 2018). In that sense, even though the lessons of two mathematics teachers fulfilled the main discipline learning outcomes, they had some weaknesses in making interdisciplinary grounding visible. For example; in the lesson of mathematics teacher 1, the topic was word problems with an unknown. Teacher gave a specific real-life problem, but in order to understand and find the solution ways of the problem, students did not need further STEM discipline to relate and inquire.

During the PLC sessions, teachers discussed collaboration ideas with facilitator. For example, biology teacher mentioned to collaborate with chemistry teacher and integrate engineering discipline for Enzymes topic. Collaboration with other subject groups indicators were not observed any of the classroom practice.

Rigor

Baseline of rigor focal point is stated as advanced research and/or theory in the STEM lesson plan preparation guide template (See Appendix D). It is important to stress that rigor relates with complex and/or challenging but above all it should provide an intriguing inquiry on students' learning process. This process should provide higher level of knowledge to students. It can be seen that most of the observed lessons did not do effective rigor activities. Most of them led students to do inquiry about the topics of the lessons, but it did not provide a scientific inquiry.

Significantly, interdisciplinarity, limitations, deep approach to learning, advanced research, connects to higher education level, extended question were the indicators that researcher considered. Below, rigor examples of teachers in their lessons were given by summarizing their activities and emphasizing the indicators that they applied. Also, researcher propounded some further rigor ideas considering taught topics.

In the below lesson, advanced research, scientific inquiry, extended questions, deep approach to learning, and beyond curriculum indicators were observable.

Chemistry teacher 1 made a good rigor example with his observed lesson. Even though there was no lesson plan and instructional sheet distributed, with in-class activities and discussions teacher provided students to do scientific inquiry and deep approaches to learning. For example, after giving theoretical information related to wave model of electromagnetic radiation, teacher started a discussion about particle property of electromagnetic radiation which was suggested by Max Planck, a theoretical physicist. In this discussion atmosphere under the moderation of teacher with his extended questions, students discovered that in order to explain subatomic substance not the theoretical physics, but Einstein's quantum physics works. Chemistry teacher 1 ended up this discussion with going beyond curriculum by connecting his lesson to higher education level. It motivated students to do advanced research about relativity theory of Einstein as homework.

Chemistry teacher 3 started her lesson with the question-answer method in order to remind students of their prior knowledge on Acid and Base. After the brainstorming, students did experiments that are related with the reaction of natural indicators and natural acids and basis. These effective experiments provided balance of theory and practice on students. However, teacher told some extended questions' answer directly related to experiment result which particularly affected the students' deep approach to learning negatively.

The lesson of physics teacher 1 had indicators of integrating technology and scientific inquiry. It also started with discussion which provides an inquiry on how students could improve James Joule's heat experiment. Moreover, teacher mentioned technological innovations into his lesson by asking questions about steam machine. Physics teacher 1 could have demanded students for designing steam machines prototypes in groups in order for lesson to be tended to be more projects based.

Physics teacher 3 applied rigor tools twice, firstly teacher emphasized theory and practice indicator by supporting groups with theoretical information related to distance of magnets while they were designing of their electricity motors. Secondly, at the end of the lesson by giving theoretical information and asking extended questions, teacher provided scientific inquiry and suggested them to think mathematically on calculation of instantaneous values of current. In this regard, in order to connect to higher education level, teacher may have asked students to work on mathematical modeling on how to show instantaneous values of current.

Biology teacher and mathematics teacher 1 did their rigor activities as a closure part of their APoKS which was emphasized and suggested method from the beginning of STEM PD program by STEM PD team. Both teachers wanted students to do mathematical modeling as extended questions in the APoKS. So, in the below lessons mathematical modeling and extended questions indicators are visible.

Biology teacher integrated the rigor part into APoKS. Students should have found a way to test their hypothesis about the authentic problem related to antibiotics. Through question-answer method, students ascertained that in order to calculate the zone of inhibition in the agar plate, they needed to know how to calculate area of a circle which was required mathematical knowledge. Also, at the end of the lesson biology teacher gave extended activity related to mathematics that contains data of effectiveness levels of different antibiotics. By using given data, students needed to draw the graphs of each which can also be seen as mathematical modeling. The extended activities only linked the lesson with interdisciplinary approach in terms of rigor focal point.

In mathematics teacher 1's lesson, the topic was word problems with an unknown. Teacher gave a specific real-life case as a problem and presented two options as solution ways. Finally he asked students to solve both options and discover which one is advantageous. During the solution processes of APoKS, teacher wanted students to find the solution with mathematical modeling by asking a question like "Could this problem be related with the graph system of equations?" The aim was to combine students' previous learning on main discipline with the current lesson.

Furthermore, students did mathematical modeling and visualized solution ways to find the best answer with other technique. On the other hand, teacher did not provide any interdisciplinarity objective in this authentic task. Moreover, task combined students' pervious learning, but did not connect any higher education level with his solution way.

All in all, seven teachers out of ten teachers attempted to fulfill at least two and at most five indicators of rigor. Only computational thinking indicators did not place in any observed lesson. The findings showed teachers did not provide rigor activities in terms of applying limitations, deep approach to learning, and connects to higher education level. The findings also showed that if the teacher aroused scientific aroused scientific inquiry related to topic and led students to do advanced research, students' interest towards to lesson and topic increased.

Relevance

Relevance in APoKS can be associated to build a bridge in terms of providing connection between disciplines and real-life context. Metaphorically, regarding their life experiences, needs, interests, and thinking skills in order students to relate their learning with real-life context to solve an authentic problem, they need to build a bridge on a specific inquiry and reasoning. In that sense, teachers' guidance during these processes is very crucial. Today's students are living in 21^{st} century and have interactions with these current global issues. As teachers, it is important to bring current issues that linked to 21^{st} century into our classrooms and provide inquiry-based learning.

Researcher considered the following indicators' effectiveness in the lessons: Interdisciplinarity, rigor in main discipline, real-life applications, caring life experiences, more than one solution, and eco-friendly.

The observed STEM lessons generally showed that the indicators of relevance were used in order for giving daily life examples of the related topics. Moreover, this process created a discussion atmosphere in the classrooms about the real-life applications of the topics. During the relevance discussions and activities, emphasis on main discipline indicator was observed in every lesson.

Three science teachers applied relevance before or/and after they did an experiment with the students.

In the chemistry and two physics lessons, with experiments students discovered some results and teachers related them with real-life context and asked extended questions. For example, physics teacher 1 used online sources indicator and opened videos in order to connect historical facts to his subject after the experiment.

In the beginning of the lesson, chemistry teacher 3 wanted students to give examples of natural acids and basis. For example, one student asked a question about the soup that the school served and whether they were still acidic or not (Last year, they discovered that school soups were acidic.). Also with experiment, students saw that glucose was basic teacher than relate its damages on our body and suggested alkali nutrition. In this regard, chemistry teacher 3 focused on caring life experiences and needs, material needs indicators to provide relevance.

At the end of the lesson, physics teacher 2 integrated interdisciplinarity and making some reminders about the main disciplines, he asked students “Thinking as an engineer, what things should be considered in flying principle of a plane?” From the variety answers of students and the prompting questions of teacher, students did deep approaches to learning about the flying principle of a plane by connecting their prior knowledge on physics such as length of runaway, effect of friction and aperture of the airfoil. Considering the second month of STEM PD workshop, as facilitator wanted teachers to design an airplane that carries the features what they have discussed, physics teacher 2 could have wanted students to do the same. In this way, students could have more deep approach to engineering and technology learning outcomes by connecting the speed and air pressure with the football, tennis and golf balls.

Physics teacher 3 had ably practiced preliminary -sustained investigation, more than one solution, have limitations, material needs, and emphasis on main discipline indicators of relevance in his lesson. He gave preliminary investigation task to students about what is electricity motor and where does it use. This investigation provisioned for students to familiarize them with the topic's real life application. In addition, students made connections easier with the given materials in designing their electricity motor prototypes.

Chemistry teacher 1 and physic teacher 4 sustained effective discussions with the students by using indicators of relevance, such as eco-friendly, limitations, and more than one solution:

For the last fifteen minutes of the lesson chemistry teacher 1 discoursed on the real life examples of electromagnetic radiation such as photocell faucets which provide water saving. Also teacher shared World Health Organization (WHO) statement on electromagnetic radiation waves that exposing under a certain dose of radiation was not harmful. In these examples, chemistry teacher 1 emphasized the eco-friendly and limitation indicators of relevance. In respect to indicators and the way they stressed, teacher had an opportunity to develop the discussions on use of photocell faucets and statement of WHO to present APoKS. Under a specific APoKS, for instance after doing preliminary research and drawing diagram, students in groups can design prototypes of photocell faucets' mechanism with given materials.

Physics teacher 4 asked questions related to daily life applications of the topic which led students think other disciplines in order to give accurate answers. For example, a student's answer to the question how they could calculate the volume of their school building was they could fulfill the whole building with gas. The answer was related with chemistry lesson. Furthermore, teacher's questions had more than one solution and it raised interest to the topic.

Biology teacher and mathematics teacher 1 and mathematics teacher 2 prepared a lesson plan that includes relevance in APoKS.

Biology teacher did an engagement activity related to historical overview about the evolution of antibiotics which then provided a relevance to APoKS and distribution of roles related to given task.

Mathematics teacher 1 presented APoKS at the beginning of the lesson. It was based on a need which met caring life experiences and needs indicator. Also task had limitations which also presented more than one solution offers. There is only one assigned role for students who would act like they were owner of a consultant firm, but the task allowed doing role distribution among group members.

Each indicator of relevance was used by teachers in different parts of their lessons. Only three teachers used relevance in their prepared APoKS. This revealed that teachers generally used relevance principle in their lesson as a discussion tool to relate their subject to real-life examples. Teacher benefited from real life applications and this shows that they did preliminary investigation on the topic.

Equity

The findings related to equity should be considered just for STEM practice of teachers. It was not intended to give a general idea on teachers' in-class teaching skills. Considering the designs of the lessons, researcher aligned evidences of equity principle from the lessons as follows:

Chemistry teacher 1 used differentiated instruction and pointed students' interests. Monitoring and enhancing group discussions by repeating students' answer and closure of the lesson indicators. In addition, from voice record analysis, question and answer part of the lesson can be considered as student-centered.

Except physics teacher 4, other three physics teacher prepared STEM lesson plans and distributed those plans to students at the beginning of the lesson.

During the lesson physics teacher 2, he showed some pictures from the projector and asked open-ended questions to enhance and sustain collective participation. Furthermore, teacher used "What if …" questions and repeating students' answer particularly.

Physics teacher 3 monitored groups during their design processes. After the activity students did self-assessment of their design.

Physics teacher 4 both asked open and closed ended questions and did a closure at the end of the lesson. On the other hand during the lesson teacher did not arrange the lesson for peer/ group work and did not use any technological tools.

Both mathematics teacher 1 and biology teacher did group work. Mathematics teacher 1 assigned groups beforehand which indicated that he did not choose random students in making groups. On the other hand, biology teacher assigned groups during the lesson and before starting to APoKS she gave two minutes to groups to discuss on task and do role distributions.

In terms of making STEM feasible in the classroom, teachers mostly applied question-answer method. Furthermore, they exhibited effective monitoring tools in these discussions. On the other hand, during observations and voice records, summative assessment was not applied by any teacher.

Lastly, it is important that students should see the lesson's goals- objectives beforehand, because with the goals- objectives teacher states the general expectations from students. Also it may be considered as check lists for students to whether at the end of the lesson they gained these objectives or not. Regarding goal-objectives, four teachers - a mathematics and three physics teachers-stated their STEM objectives on worksheets and distributed to students.

Approaches to authentic problems of knowledge society (APoKS)

During the initial STEM PD program, teachers had learning and practice experiences on many different APoKS that was designed and implemented by the STEM PD team. In every PD seminar-workshop, the PD team emphasized that the chosen authentic problem needed limitations and have more than one solution. By teachers who guide them to take responsibilities and do reasoning in these solution processes, APoKS can feature and improve students' problem solving and higher order skills.

From the classroom practice forms and voice records, neither chemistry teachers nor physics teachers specified any APoKS. Regarding STEM lesson plan template, these teachers focused only on the content of the lesson part. All the asked questions have specific single valid answers.

Chemistry teacher 1 and physics teacher 2 highlighted every key point with using many of their indicators in their lessons effectively; but the lessons were not prepared on specific APoKS. In that sense, there was no variety of product or solution for any problem, but the content of the lesson prepared well and satisfying with rhetorical questions.

Chemistry teacher 2 and physics teachers' lessons were placed in the laboratory and students did experiments, so there were results at the end of the experiments but they were not offering solution to any APoKS.

Under the APoKS title, physics teacher 3 asked students in groups to make and present their electricity motors as a project. If teacher created any authentic to relate these electricity motors, then it would have been an effective APoKS example, but teacher did not give any limitations or provide a role distribution of a specific task.

Apart from examples related to relevance of topic with real life physics teacher 4 did not focus on any specific problem and questioning its solution.

Mathematics teacher 1 and biology teacher were fulfilled role distribution and specific problem requisites of APoKS without having more than one solution and limitation. For instance, biology teacher introduced APoKS to the students as they were a specific group of researcher who comprised of biostatistics and microbiologist had worked in 1990s. After group discussion, group representative made inferences about the two cases in the task.

To sum, generally teachers applied focal points effectively in their teaching, but the core element of STEM: InTeachFramework which is APoKS did not highlighted and applied as it is required.

Findings related to the contribution of PD based on STEM to the teaching philosophy of secondary mathematics and science teachers according to their perception.

One of the purposes of this research is to introduce a sustainable professional development program prototype to mathematics and science teachers and get the participated teachers' opinions about this program prototype. In the last seminar day, teachers wrote reflections on what sort of improvements they observed about themselves during this eight-month long STEM PD. There are 17 reflections that were written by teachers who attended this STEM PD. In the four reflections, teachers stated that this STEM PD did not change their teaching philosophy. Moreover, one teacher did not emphasize any focal point and its indicator in his reflection. In Table 6, indicators that were stated by 12 teachers in their reflections were given with highlighted frequencies.

Table 6
Indicators that were stated in reflections

interdisciplinarity	rigor	relevance	equity
•STEM disciplines •main discipline and connections of other disciplines (10) •integrating technology (4) •integrating engineering (5) •collaboration with other subject groups (5)	•interdisciplinarity (7) •emphasis on main discipline (3) •beyond curriculum (2) •scientific inquiry (4) •mathematical modeling (2) •extended questions (2) •doing research (3) •limitations (2)	•real-life application (8) •more than one solution (4) •exploring one's interest (3) •caring life experiences and needs (2) •eco-friendly (2) •online sources (2) •social media-news (1)	•student-centered (5) •rubric preparation (2) •active learning (5) •question-answer method (3) •planning (2)

Detailed explanation of the Table 6 was given under each focal point title.

Interdisciplinarity

In the twelve reflections, the most mentioned indicators were main discipline and connections of other disciplines, science, and mathematics. It was emphasized that this eight-month long STEM PD helped them to increase their awareness on the importance of interdisciplinarity in teaching. Ten teachers stated that they were already familiar with the idea of the interdisciplinarity in terms of mathematics and science disciplines. After PD, they grasped the importance of engineering and/or technology indicators as well. Furthermore, they started to focus on interdisciplinary

grounding while they were planning their lessons. A chemistry teacher expressed this situation as: “During the eight months process, I started to integrate other disciplines and engineering acquisitions into my chemistry lesson when it is relatable.”
In addition, some teachers described how their perception improved in terms of interdisciplinarity by emphasizing different indicators. For example, five teachers emphasized the collaboration with other subject groups. Related to that, one teacher said:

> In terms of interdisciplinary grounding, it is not possible to be component in every subject field. By means of this STEM PD, I felt that doing group work and having conversation with other subject group teachers on specific tasks and topics during PD workshops show me the importance of collaboration.

Another teacher addressed the relationship between permanent learning and interdisciplinarity:

> Considering the whole process of STEM PD, my most gained idea is this: “When I combine my lesson with other disciplines, it leads a more significant and permanent learning”.

Rigor

In the second module of STEM PD seminar-workshop and PLC meeting, the focus point of the month was rigor in main discipline. In this consideration, researcher focused on how teachers’ perceptions changed regarding their own discipline. According to the data that is analyzed from PLC meetings and reflections, teachers referred rigor by combining it with interdisciplinarity most.

One teacher shared her motivation in doing rigor activities as follows:

> When the unit has finished, during the review part having rigor questions help to go beyond curriculum which is great!

Same teacher also showed her understanding on the holistic approach between interdisciplinarity and rigor in an effective way:

> Perhaps one subject teacher's own qualification in her/his discipline is a prerequisite before opening doors to other disciplines.

Most of the teachers stated they are mainly applying rigor activities in their classes as a part of STEM. Related to that, a teacher made a sincere statement:

> Without recognizing I started to do rigor activities in my lessons and chew it over more. For example in polygons, while I was giving formulas related to element numbers, I constantly asked questions as "Why it is like that?", "Okay, we found this, how can we relate it with this formula?" and made a question-answer lesson with these extended questions. At the end of the lesson when students told "Those were always linked to each other. How easy it was." both sides (me and them) were peaceful and tired.

Relevance

According to analyzed data, relevance had an effect on teachers as an exploration in their teaching philosophy. In order to find the relevancy of the topic, teachers stated that they started to do research and discussions with or/and within disciplines. A teacher explains this change in his teaching philosophy as:

> I aspired to be more planned and readier to my lessons. I searched for a while and after this research I prepared a STEM lesson plan diagram and changed my old methods. I featured in student-centered approach more. In that way I started to include real life problems and applications into my lesson more by integrating physics experiments into those problems' solution ways. STEM - an eco-friendly system - has taught me to look at different perspectives and to see what is happening around me as I understand its philosophy.

One of the teachers used a holistic approach in his lesson emphasizing both relevance and rigor in his comment:

> I integrated a current problem into my lessons in order students to produce solutions by doing mathematical modeling. Also I provided them to formulize their models.

Equity

Underneath equity principle, student-centered and active learning indicators are the most highlighted ones. Teacher explained how technology and internet provide these two indicators as follows:

> STEM provides an understanding for me on integrating technology into my lessons. I was seeing internet and computer technologies as negative tools that

making students non-inquiry individuals. Nevertheless, under STEM lessons, integrating technology help students to discuss and find solution ways to real-life problems. Internet is also efficient tool for students to find different sources and discussed them in class. Shortly, these tools provide active learning and the lessons become more student-centered.

Approaches to authentic problems of knowledge society (APoKS)

Teachers approach to APoKS as a project that needs vain research. Teachers generally agreed that APoKS provided students higher order skills and problem solving skills which they can make better connections of learnt subjects with authentic problems of 21st century.

Especially STEM projects that involve engineering help students to understand there is not always one solution for a specific problem.

One teacher, apart from her development in teaching philosophy, emphasized a difficulty:

My first (and unfortunately only) STEM lesson plan was really fun regarding its preparation and implementation processes. I felt proud inwardly when I make students realize that civil engineering is something different than looking at the columns at construction. While preparing this lesson plan I collaborated with my former student who is a graduate student in civil engineering. We talked in hours about how can we integrate and explain to students in the lesson. In my second project when I collaborated with my colleague, I realized

> that in order to focus and plan a STEM lesson, I need much more information, energy, and most importantly time.

The time problem that is emphasized in the above comment was also stated by other teachers. For example another teacher underlined the same difficulty with given a reason:

> From my point of view, STEM seminars and workshops were so fruitful and have affected my career in a positive way. Unfortunately, our intense working conditions related to vision of school which is a university exam-centered, I feel that I could not spare my time to STEM activities as necessary.

To conclude, according to some written reflections and discussions in the PD seminars-workshops and especially in PLC meetings, teachers generally mentioned about their lack of time for preparation. In that sense, even though, they can see the positive effects of doing STEM principles in the classrooms, they could not find any time to prepare and apply an effective APoKS in their classrooms.

CHAPTER 5: DISCUSSIONS

Introduction

This chapter provides an overview of the study and discussions of main findings in reference to literature. The implications for practice and further research are also clarified. Lastly, limitations of this study are given.

Overview of the study

The overall intention of the study was to describe a STEM PD program and designate if there were any effects of this PD on secondary science and mathematics teachers in terms of their classroom practices and teaching philosophy. The sample consisted of 27 science and mathematics teachers. Based on the research question 2 and 3, main data were obtained from 10 teachers for classroom practices and 17 teachers for reflections.

The conceptual framework of this study was STEM: InTeachFramework, (See Figure 1 in Chapter 2) which aims to offer solutions for authentic problems of knowledge society (APoKS) that are complex and dynamic problems of the twenty-first century in the schools. The general relationship among focal points of this study, which are interdisciplinarity, rigor, relevance, and equity, can be described with holistic approach. Integrative STEM education is placed under pedagogical STEM and defined as approaches that investigate the relation between/among two or more of the STEM subjects, and/or between a STEM subject and one or more school subjects in teaching and learning with (Sanders, 2009). Within this context, interdisciplinarity is an initial focal point that provides a bridge to build rigor and relevance focal points respectively. Equity principle is the pedagogical tools which make STEM feasible in the school environment.

This case study was guided by the following questions:

1. How can this initial STEM PD program be described?
2. How does the initial STEM PD affect the classroom practices of mathematics and science teachers?
3. What are the indicators that affect mathematics and science teachers' teaching philosophy according to their perception after taking the initial STEM PD program?

Major findings

Major findings of this qualitative study were given under three themes: STEM principle and teachers' classroom practices, development of interdisciplinarity, rigor, and real-life application through STEM PD, and attitudes towards implementation of APoKS in the classroom.

STEM principles and teachers' classroom practices

- PD provided teachers to show their general understanding on STEM principles explicitly in their classroom practices.
- Mathematics and science teachers partially presented STEM principles as a holistic approach under STEM: InTeachFramework.

- There was integration of mathematics and science disciplines in their lesson contents. Technology and engineering disciplines were placed as to maintain class discussions about real-world problems but not linked with future jobs.

Development of interdisciplinarity, rigor, and real-life application through STEM PD

- STEM PD provided developments on mathematics and science teachers' teaching philosophy by integrating interdisciplinarity and rigor principles into their lessons.
- Teachers have increased their awareness through the prototype of the PD program they participated in.
- Real-life applications related to teacher's main disciplines and connections of them with other disciplines were the most adopted indicators.

Attitudes towards implementation of an authentic problem of the knowledge society in the classroom

- Teachers provisioned relevance of authentic problems with discussions in their classroom environment by integrating interdisciplinary contexts.
- The desired solution offers and related products for APoKS that emphasized in STEM PD were not fulfilled.
- There was no cooperation of teachers for any APoKS application the classrooms.

Discussion of major findings

The details and possible reasons of the findings are mentioned and discussed below.

STEM principles and teachers' classroom practices

PD provided teachers to show their general understanding on STEM principles explicitly in their classroom practices. As Kennedy and Odell (2014) stated effective pedagogic STEM in the classrooms can be done through a teaching approach that altered form traditional and teacher-centered to active and student-centered. Teachers provided inquiry based approaches to learning in their classroom practices. They supported their content of the lessons with STEM disciplines in order to improve students' abilities to ask questions, interpret data, solve problem and communicate findings by connecting them with real world (McDonald, 2016). Also, the results showed that with the discussed equity tools during PD, teachers guided students to become innovative thinkers with encouraging them to apply creative problem-solving techniques, do teamwork and collaboration (Roberts, 2013b). On the other hand, scientific inquiry which is linked with rigor discipline assisted students to think like science people and structure their knowledge (Schneider, Krajcik, Marx, & Soloway, 2002). Teachers did not provide rigor activities effectively in terms of applying limitations, deep approach to learning, and connects to higher education level.

For practitioners and researchers who follow InTeachFramework as a route map, there is an important point to be aware of. In the school eco-system, disciplines are not integrated with each other by themselves; teachers and students are the ones that provide this integration among disciplines at the school level (Aşık et al., 2017).

Teachers partially presented STEM principles as a holistic approach under InTeachFramework. Collaboration ideas that were discussed by different subject groups' teachers in PLC sessions promoted them to connect their main disciplines' contexts to other disciplines' as rigor tools. On the other hand, planned collaborations with other subject groups' teachers during these sessions were not observed in the classroom practices. In that sense, interdisciplinarity principle appeared partially in the lesson content of mathematics and science teachers' classroom practices. In order for preparing an interdisciplinary grounding lesson or unit to facilitate teacher to encourage students and promote their learning skills, at least two disciplines should be comprised with using new skills and knowledge from these disciplines (Robinson, 1994 as cited in Ozacar Helvaci, 2018). Classroom practices of teachers showed that there was integration of mathematics and science disciplines in their lesson contents. As it was also stated many times in STEM PD program, STEM education includes not only mathematics and science, but also technology and engineering fundamentals which promote students to develop their skills that are required for future jobs (Roberts, 2013a). Moreover, notion of integration in the modern conception of STEM education can be defined by emphasizing the purposeful integration of different disciplines in order to solve real-world problems (Sanders, 2009; Breiner, Harkness, Johnson, & Koehler, 2012). In that sense technology and engineering disciplines were placed as to maintain class discussions about real-world problems but not linked with future jobs.

Development of interdisciplinarity, rigor, and relevance applications through STEM PD

For a teacher who wants to follow InTeachFramework as a route map for his/her teaching career, it would be useful to collaborate with teacher educators in the long-term and circulated academic year because a non-prepared teacher's implementation on innovative practices may have harmful effects on student's learning process (Capraro et al., 2016). STEM PD provided developments on mathematics and science teachers' teaching philosophy by integrating interdisciplinarity and relevance principles into their lessons. It was stated that the seminars and workshops endorsed an educational model that includes contextualized problem-solving activities and real-world applications and showed them how to integrate this model into their classroom practices (Avery & Reeve, 2013). Thus, in order to state an educational reform as successful with its implementations, the focus may include the chaining teachers' beliefs about effective instructional approaches (McDonald, 2016). In this regard, real-life applications related to teacher's main disciplines and connections of them with other disciplines were the most adopted indicators.

The other outcome obtained from this research is to emphasize the importance of sharing the experiences in their PD. Teachers also expressed their contentment on working together and exchanging ideas (Tataroğlu, Taşdan & Çelik, 2014). Another finding of the study is that teachers have increased their awareness through the prototype of the PD program they participated in and expressed their opinions about self-criticism and organizing their own teaching (Tataroğlu, Taşdan & Çelik, 2014).

Attitudes towards implementation of an authentic problem of the knowledge society in the classroom

A coherent argument regarding the changes that are experienced in 21st century's world is having and implementing a structured curriculum under STEM education's interdisciplinary contexts that emerge from 21st century authentic problems of knowledge society (Aşık et al., 2017). Even though the school gives importance to national exams, teachers provisioned relevance of authentic problems with discussions in their classroom environment by integrating interdisciplinary contexts. In that sense, STEM PD gained an understanding on necessity of APoKS for teachers in school environment.

On the other hand, authentic learning-fundamentally based on real-world by focusing complex problems and their solutions, role distribution tasks, and problem-based activities (Lombardi, 2007) - should be done in a leaning environment that includes 'real world' application or discipline: managing a city, building a house, flying an airplane, setting a budget, solving a crime (Downes, 2007). All these applications require limitations that link the problem to the objectives set/chosen by the teacher. In that sense, there were no limitations for desired solution offers and related products for APoKS. Teachers who participated in this study took such an initiative in their practice for the first time. Related to designing and implementing APoKS, teachers stated in their reflections that APoKS requires vain research. Therefore, they could be hesitated to design and implement authentic problems in their classrooms (Arafah, 2011; Bozkurt Altan & Ercan, 2016).

Authentic problems of knowledge society such as global warming, cancer, traffic, and machine-human relationships show complex and dynamic structure. Having expertise in different fields under this complex and ever-changing structure is considered as a situation that beyond the competences of individuals and it requires the cooperation of individuals (Corlu, 2017b, p. 6). According to results, although collaboration plans for STEM practices discussed among mathematics and science teachers during PLC meetings, there was no cooperation of teachers for any APoKS application the classrooms. The reason behind such a result could be related to time. Time can be seen as one of the obstacles to apply true interdisciplinary teaching in terms of collaboration between subject teachers and implementation of it in the classroom (Kaszczak, 2013). The results show that teachers could not find enough time for collaboration because of their intense workload in terms of preparing students for national exams. The discipline-based external examinations cause pressure on teachers to teach for the discipline standards (as cited in Ríordáina, Johnstonb, & Walshec, 2016).

Implications for practice

Based on the findings of this study, the following implications for practice are suggested for effective STEM practices. Firstly, the schools' administrators can provide adequate preparation time for teachers to do research, collaborate, prepare, and implement STEM practices in their lessons. Besides, teachers who want to integrate STEM: InTeachFramework into their classroom practices can spend more time with STEM experts and practitioners for preparation and application of APoKS. Secondly, schools, which aim to enforce STEM practices, need to provide long-term and sustainable PD opportunities for teachers rather than short and one-shot PD events. Additionally, STEM experts and practitioners can be consulted to find out about the implementation of STEM practices. Finally, curriculum flexibility in terms of interdisciplinarity between mathematics and science disciplines can enhance the effectiveness of STEM education. However, it should be noted that in order for STEM education to be effective, primarily disciplinary grounding should be clear and established.

Implications for further research

The study explored the impact of STEM PD on secondary mathematics and science teachers in terms of their classroom practices and teaching philosophies. So, the study only focused on the experiences of secondary mathematics and science teachers. For the future researchers, the study can focuse on the change in students' authentic learning experiences. Also, the present study can be implemented in the middle school level for middle school teachers. STEM education comprises not only mathematics and science teachers, but also technology and design teacher. In this regard technology and design teachers can be included into STEM PD programs as participants. Using a longitudinal study, in order to assess the long-term impact of STEM PD on teachers' classroom practices can be observed again after their one-year of experience in STEM education. Lastly, in order to make a comparison with the results of this current study, the future researcher can explore this study under the same PD context with another school that has different vision.

Limitations

Despite the significance of this study in terms of STEM's rare application at the time of the research in Turkey, it holds some limitations. The gathered data of this study and its effectiveness can be compared and evaluated with the data mainly gathered from U.S. schools; only a few studies have been done in Turkey in terms of effectiveness of STEM PD on secondary mathematics and science teachers. Another limitation of this study is that there are only a couple of schools which provided continuous STEM PD programs for their mathematics and science teachers and to integrate STEM subjects into their curriculum for the first time in Turkey. In that sense, developments in mathematics and science teachers' classroom practices and teaching philosophy described and explained by looking a few domestic data; but mainly at foreign data and results.

The case study is not intended to build a general theory about the secondary science and mathematics teachers' classroom practices and perception on pedagogic STEM education and STEM PD. The main data gathered from few participants and they represent only that group. Also, the participants in the program were the secondary mathematics and science teachers who work in a school which has a reputation with its high academic achievement in the national high-stakes exams. Although the teachers participated in this STEM PD were enthusiastic about creating new ideas, the school's focus context based on national curriculum and related applications.

REFERENCES

Akaygun, S. & Aslan-Tutak, F. (2016). STEM images revealing stem conceptions of pre-service chemistry and mathematics teachers. *International Journal of Education in Mathematics, Science and Technology*, *4*(1), 56-71. doi:10.18404/ijemst.44833

Aksit, N. (2007). Educational reform in Turkey. *International Journal of Educational Development, 27*(2), 129-137. doi: 10.1016/j.ijedudev. 2006.07.011

Alptekin, Y. (2006). Can progressive education be translated into a progressive idea?: Dewey's report on Turkish education (1924). *International Journal of Progressive Education*, *2*(2), 9-21.

Arafah, M. M. (2011). But what does this have to do with science? Building the case for engineering in K-12. (Unpublished master's thesis.). Cleveland State University, OH.

Aşık, G., Doğança Küçük, Z., Helvaci, B., & Corlu, M. S. (2017). Integrated teaching project: A sustainable approach to teacher education, *Turkish Journal of Education*, *6*(4), 200-215. doi:10.19128/turje.332731

Avery, Z. K., & Reeve, E. M. (2013). Developing effective STEM professional development programs. *Journal of Technology Education*, *25*(1), 55-69.

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report*, *13*(4), 346-559.

Bekhet, A. K., & Zauszniewski, J. A. (2012). Methodological triangulation: An approach to understanding data. *Nurse Researcher, 40*(2), 40-43. doi: 10.7748/nr2012.11.20.2.40.c9442

Berry, B. (2015). The dynamic duo of professional learning = collaboration and technology. *Phi Delta Kappan, 97*(4), 51–55. Retrieved from http://journals.sagepub.com/doi/pdf/10.1177/0031721715619920

Bicer, A., Navruz, B., Capraro, R. M., Capraro, M. M., Oner, T., & Boedeker, P. (2015). STEM schools vs. non-STEM schools: Comparing students'matematics growth rate on high-stakes test performance. *International Journal on New Trends in Education and Their Implications, 6*(1), 138-150.

Bozkurt Altan, E., & Ercan, S. (2016). STEM education program for science teachers: Perceptions and competencies. *Journal of Turkish Science Education, 13*(Special Issue), 103-117.

Breiner, J., Harkness, S., Johnson, C., & Koehler, C. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics, 112*(1), 3-11.

Capraro, R. M., Capraro, M. M., Morgan, J., Scheurich, J., Huggins, K., Corlu, M. S., Younes, R., & Han, S. (2016). The impact of sustained professional development in STEM project-based learning on district outcome measures. *The Journal of Educational Research, 109*(2), 181-196. doi:10.1080/00220671.2014.936997

Cetinkaya, G. (2014). Growth, quality, internationalization: Roadmap for Turkish Higher Education) (in Turkish), YOK (Higher Ed Council) Publications, n.2014/2, Eskisehir, Turkey.

Cohen, D., & Crabtree, B. (2006, July). Qualitative research guidelines project. Retrieved from http://www.qualres.org/HomeProl-3690.html

Coleman, W. (2005). *Educating Americans for the 21st century*. Prepared by the Center for the Study of Mathematics Curriculum. Retrieved from http://csmc.missouri.edu/PDFS/CCM/summaries/EducatingAmericans.pdf

Corlu, M. S., Capraro, R. M., & Capraro, M. M. (2014). Introducing STEM education: Implications for educating our teachers for the age of innovation. *Education and Science, 39*(171), 74-85.

Corlu, M. S. (2017a). Bilimsel yöntemin dönüşümüne ait öngörülerin öğretime kaçınılmaz etkileri. In Türkiye Özel Okullar Derneği, *Eğitimde öngörüler* (pp. 227-231). Istanbul, TR: Golden Medya.

Corlu, M. S. (2017b). STEM: Bütünleşik öğretmenlik çerçevesi [STEM: Integrated teaching framework]. In M. S. Corlu, & E. Çallı (Eds), *STEM Kuram ve Uygulamaları* (pp. 1-10). İstanbul, Turkey: Pusula.

Corlu, M. S. (2018). STEM bütünleşik öğretmenlik: Yaparak öğrenmeden üreterek öğrenmeye [STEM integrated teaching: From learning by doing to learning by making]. Harvard Business Review, 7, 102-108.

Craft, A. (2000). *Continuing professional development: A practical guide for the teachers and schools* (2nd ed.). New York, NY: The Open University.

Creswell, J. W. (2007). Philosophical, paradigm, and interpretive frameworks. In J. W. Creswell (Eds.), *Qualitative inquiry and research design: Choosing among five approaches* (2nd ed., pp. 15-34). Thousand Oaks: Sage Publications.

Darling-Hammond, L. (2000). Teacher quality and student achievement: A review of state policy evidence. *Educational Policy Analysis Archives, 8*(1), 1-44.

Desimone, L. M., Porter, A. C., Garet, M. S., Yoon, K. S., & Birman, B. F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. *Educational Evaluation and Policy Analysis, 24*(2), 81–112. doi:10.3102/01623737024002081

Dogan, S., Pringle, R., & Mesa, J. (2015). The impacts of professional learning communities on science teachers' knowledge, practice and student learning: A review. *Professional Development in Education*, *42*(4), 569-588. doi:10.1080/19415257.2015.1065899

Downes, S. (2007). *Emerging technologies for learning*. Coventry, U.K.: Becta. Retrieved from http://www.mmiweb.org.uk/publications/ict/emerging_tech02.pdfDuFour, R.,

DuFour, R., Eaker, R., & Many, T. (2006). *Learning by doing: A handbook for professional learning communities at work*. Bloomington, IN: Solution Tree.

Dugger, W. (2010). Evolution of STEM in the United States. In *Technology Education Research Conference*. Queensland, Australia.

Educational Testing Service. (2004). Where we stand on teacher quality. *In Teacher Quality Series,*1–13. Retrieved from https://www.ets.org/Media/Education_Topics/pdf/teacherquality.pdf

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*, *62*(1), 107–115. doi: 10.1111/j.1365-2648.2007.04569.x

Empowering Students: The 5E model explained, (n.d.). Retrieved from https://lesley.edu/article/empowering-students-the-5e-model-explained

European Commission. (2012, November 11). *Supporting the teaching professions for better learning outcomes*. Strasbourg. Retrieved from http://eu2013.ie/media/eupresidency/content/documents/Support-the-Teaching-Professions-for-Better-Learning-Outcomes.pdf

European Commission. (2013, July). *Supporting teacher competence development for better learning outcomes*. Retrieved from http://ec.europa.eu/education/policy/school/doc/teachercomp_en.pdf

European Schoolnet (2018). *Science, technology, engineering and mathematics education policies in Europe.* Scientix Observatory report. European Schoolnet, Brussels.

Fraenkel, J. R., & Wallen, N. E. (2006). *How to design and evaluate research in education*. Boston, U.S.A: McGraw-Hill.

Gay, L. R., Mills, G. E., & Airasan, P. (2006). *Educational research: Competencies for analysis and applications*. New Jersey, U.S.A: Pearson Education, Inc.

Gibson, W. J., & Brown, A. (2009). *Working with qualitative data.* London, UK : Sage Publications. doi:10.4135/9780857029041

Girgin, Ş. (2018). *Ethnographic case study of early STEM education: Investigating students' authentic learning experience* (Unpublished master's thesis). Yıldız Technical University, İstanbul, Türkiye.

Grbich, C. (2012). *Qualitative data analysis: An introduction* (2nd ed.). London, UK: Sage Publications.

Grossman, G. M., Sands, M. K., & Brittingham, B. (2010). Teacher education accreditation in Turkey: The creation of a culture of quality. *International Journal of Educational Development, 30*(1), 102-109. Retrieved from http://yoksis.bilkent.edu.tr/pdf/files/10.1016-j.ijedudev.2009.08.003.pdf

Guskey, T. R. (2000). *Evaluating professional development*. Thousand Oaks, CA: Corwin Press.

Guskey, T. R., & Yoon, K. S. (2009). What works in professional development? *Phi Delta Kappan, 90*(7), 495–500. doi:10.1177/003172170909000709

Hamos, J. E., Bergin, K. B., Maki, D. P., Perez, L. C., Prival, J. T., Rainey, D. Y., Rowell, H. G., &VanderPutten, E. (2009). Opening the classroom door: Professional learning communities in the math and science partnership program. *Science Educator*, *18*(2), 14–24.

Hanushek, E. A. (2002). Teacher quality.In L. T. Izumi & W. M. Evers (Eds.), *Teacher quality* (pp. 1-12). Palo Alto, CA: Hoover Press.

Hernandez, P. R., Bodin, R., Elliott, J. W., Ibrahim, B., Rambo-Hernandez, K. E., Chen, T. W., & de Miranda, M. A. (2014). Connecting the STEM dots: Measuring the effect of an integrated engineering design intervention. *International Journal of Technology and Design Education*, *24*(1), 107-120. doi:10.1007/s10798-013-9241-0

Hopkins, D., & Stern, D. (1996). Quality teachers, quality schools: International perspectives and policy implications. *Teaching & Teacher Education*, *12*(5), 501–517.

Hunzicker, J. (2010). Characteristic of effective professional development: A checklist. Retrieved from http://files.eric.ed.gov/fulltext/ED510366.pdf

İlğan, A. (2013). Öğretmenler için etkili mesleki gelişim faaliyetleri [Effective professional development for teachers]. *Uşak Üniversitesi Sosyal Bilimler Dergisi*, 41-56.

Jackson, C., & Bruegmann, E. (2009). Teaching students and teaching each other: the importance of peer learning for teachers. *American Economic Journal: Applied Economics, 1*(4), 85-108. Retrieved from http://www.jstor.org/stable/25760183

Kaszczak, L. (2013). *Examining a math-science professional development program for teachers in grades 7-12 in an urban school district in New York State* (Unpublished doctoral dissertation). Retrieved from ProQuest Dissertations. (UMI No. 3664220)

Kennedy, T. K., & Odell, M. R. L. (2014). Engaging students in STEM Education. *Science Education International, 25*(3), 246-258.

Kersaint, G., Ritzhaupt, A. D., & Liu, F. (2014). Technology to enhance mathematics and science instruction: Changes in teacher perceptions after participating in a yearlong professional development program. *Journal of Computers in Mathematics and Science Teaching, 33*(1), 73-101.

Labov, J.B., Reid, A.H., & Yamamoto, K.R. (2010). Integrated biology and undergraduate science education: A new biology education for the twenty-first century? *CBE—Life Sciences Education, 9*, 10-16.

Laws, K., & McLeod, R. (2004). Case study and grounded theory: Sharing some alternative qualitative research methodologies with systems professionals. *Proceedings of the 22nd International Conference of the Systems Dynamics Society*, 1-21.

Lincoln, Y.S., & Guba, E.G. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage Publications.

Lombardi, M. M. (2007). Authentic learning for the 21st century: An overview. *Educase Learning Initiative,1*. Retrieved from http://www.educause.edu/ir/library/pdf/ELI3009.pdf.

Loucks-Horsley, S., Stiles, K., & Hewson, P. (1996). Principles of effective professional development for mathematics and science education: A synthesis of standards. *NISE Brief* 1(1), Madison, WI: University of Wisconsin.

Loucks-Horsley, S., Hewson, P.W., Love, N., Mundry, S., & Stiles, K. E. (2003). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Sage Publications.

Loving, C. C., Schroeder, C., Kang, R., Shimek, C., & Herbert, B. (2007). Blogs: Enhancing links in a professional learning community of science and mathematics teachers. *Contemporary Issues in Technology and Teacher Education*, *7*, 178–198.

Mack, L. (2010). The philosophical underpinnings of educational research. *Polyglossia, 19*, 5-11. Retrieved from http://en.apu.ac.jp/rcaps/uploads/fckeditor/publications/polyglossia/Polyglossia_V19_Lindsay.pdf

McDonald, C. V. (2016). STEM Education: A review of the contribution of the disciplines of science, technology, engineering and mathematics. *Science Education International*, *27*(4), 530-369.

Menezes, L. (2011). Collaborative research as a strategy of professional development of teachers. In B. Ubuz (Ed), *Proceedings of the 35th Int. Conference on the Psychology of Mathematics Education, 3,* 225-232, Ankara, Turkey.

Merriam., S. B. (1995). What can you tell from an N of l ?: Issues of validity and reliability in qualitative research. *PAACE Journal of Lifelong Learning*. *4,* 50-60.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2013). *Qualitative data analysis* (3rd ed.) [Google Books version]. Retrieved from https://books.google.com.tr/books?id=3CNrUbTu6CsC

Ministry of National Education (MoNE). (2016). *STEM education report [STEM Eğitimi Raporu]*. Ankara, TR.

National Commission on Teaching & America's Future. (2010). *STEM teachers in professional learning communities: A knowledge synthesis.* Retrieved from https://www.wested.org/online_pubs/resource1097.pdf

National Partnership for Education and Accountability in Teaching. (2000). Revisioning professional development: What learner centered professional development looks like. Oxford, OH: National Assessment of Educational Progress

National Staff Development Council. (2001). *Standards for staff development* (revised). Oxford, OH: Author.

Neil-Burke, B. M. (2016). *Toward the design and implementation of STEM professional development for middle school teachers: An interdisciplinary approach* (Unpublished doctoral dissertation). Retrieved from ProQuest Dissertations. (UMI No. 10188572)

Nelson, K. G. (2006). *Developing a professional learning community among mathematics teachers on two Montana Indian reservations*. Montana State University, Bozeman, Montana. Retrieved from https://scholarworks.montana.edu/xmlui/bitstream/handle/1/1945/NelsonK1206.pdf?sequence=1

OECD. (2013). E*ducation policy outlook highlights: Turkey*. Paris: OECD. Retrieved from http://www.oecd.org/edu/EDUCATION%20POLICY%20OUTLOOK%20TURKEY_EN.pdf

OECD. (2015). *Education policy outlook 2015: Making reforms happen*. Paris: OECD. doi:10.1787/9789264225442-32-en

Oehrtman, M., Carlson, M., & Vasquez, J. A. (2009). Attributes of content-focused professional learning communities that lead to meaningful reflection and collaboration among math and science teachers. In S. Mundry, K. E. Stiles, & P. Keeley (Eds.), *Professional learning communities for science teaching: Lessons from research and practice* (pp. 89–106). United States: National Science Teachers Association.

Orrill, C. H., Geisler, S., Brown, R., & Brunaud-Vega, V. (2008). Questioning teacher goals in professional development: Do goals really make a difference? *International Conference for the Learning Sciences (ICLS),3*, 105-106

Ozacar Helvaci, B. (2018). *Interdisciplinary STEM education: Exploring technology and engineering integration in mathematics and science classes* (Master's thesis). Retrieved from CoHE Thesis Center Database. (Accession No. 515178)

Ozoglu, M. (2010). Türkiye'de öğretmen yetiştirme sisteminin sorunları. *Foundation for Political,Economic and Social Research (SETA), 17*, 1-34.

Patel, N. V. (2003). A holistic approach to learning and teaching interaction: Factors in the development of critical learners. *International Journal of Educational Management, 17*(6), 272-284. doi:10.1108/09513540310487604

Ríordáina, M.N., Johnstonb, J., & Walshec, G., (2016). Making mathematics and science integration happen: key aspects of practice. *International Journal of Mathematical Education in Science and Technology, 47*(2), 233-255. doi:10.1080/0020739X.2015.1078001

Roberts, S. A. (2013a). *Preferred instructional design strategies for preparation of pre-service teachers of integrated STEM education* (Unpublished doctoral dissertation). Retrieved from ProQuest Dissertations. (UMI No. 3576657)

Roberts, S. A. (2013b). STEM is here, now what? *Technology and Engineering Teacher 75*(1), 22-27.

Sanders, M. (2009). STEM, STEM education, STEM mania. *Technology Teacher, 68*(4), 20–26.

Schneider, R. M., Krajcik, J., Marx, R. W., & Soloway, E. (2002). Performance of students in project-based science classrooms on a national measure of science achievement. *Journal of Research in Science Teaching*, *39*(5), 410-422. doi: 10.1002/tea.10029

Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research*, *2*(1), 28-24. doi:10.5703/1288284314653

Strong, M. (2011). What do we mean by teacher quality? . In M. Strong (Ed.), *The highly qualified teacher: What is teacher quality and how do we measure it?* (pp. 12–17). New York, NY: Teachers' College Press.

Systems Approach for Better Education Results. (2012, July 11). *What matters most in teacher policies? A framework for building a more effective teaching profession.* Washington, DC: World Bank.

Tarman, B. (2010). Global perspectives and challenges on teacher education in Turkey. *International Journal of Arts and Sciences*, *3*(17), 78–96.

Tataroğlu Taşdan, B., & Çelik, A. (2014). Matematik öğretmenlerine yönelik bir mesleki gelişim programı prototipi. *e-Journal of New World Sciences Academy*, *9*(3), 323–340. doi:10.12739/NWSA.2014.9.3.1C0621

Teaching Institute for Excellence in STEM. (2010). *What is STEM education?* Retrieved from http://www.tiesteach.org/stem-education.aspx.

Tsupros, N., Kohler, R., & Hallinen, J. (2009). *STEM Education in Southwestern Pennsylvania. Report of a project to identify the missing components*. Pennsylvania: Leonard Gelfand Center for Service Learning and Outreach at Carnegie Mellon University and The Intermediate Unit 1 Center for STEM Education.

Turan, S. (2000). John Dewey's report of 1924 and his recommendations on the Turkish educational system revisited. *History of Education, 29*(6), 543-555

White, M. & Marsh, E. (2006). Content analysis: A flexible methodology. *Library Trends,55*(1). doi:55. 10.1353/lib.2006.0053.

Yin, R. K. (1994). *Case study research: Design and methods* (2nd ed.). Thousand Oaks: Sage Publications.

Yin, R. K. (2003). *Applications of case study research* (2nd ed.). Thousand Oaks: Sage Publications.

Yoon, K. S., Duncan, T., Lee, S. W.-Y., Scarloss, B., & Shapley, K. L. (2007). *Reviewing the evidence on how teacher professional development affects student achievement* (Issues & Answers Report, REL 2007–No. 033). Washington, DC: U.S. Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, Regional Educational Laboratory Southwest. Retrieved from https://ies.ed.gov/ncee/edlabs/regions/southwest/pdf/REL_2007033.pdf

APPENDIX A: PD Seminar-Workshop Observation Form

Observer Name and Surname:

Name of Institution or School: **Seminar Date:** **Workshop:**

1) Information on pre-seminar planning (Notes taken during the Saturday morning interview and Italian rehearsal)

2) Seminar observation

Time	**Seminar Facilitator:** (A brief note on what the facilitator does)	**Participant Teachers:** (Detailed notes related to participant teachers' actions. With their names, if possible)	**Emphasis on focus of the month**

APPENDIX B: PLC Meeting Observation Form

Date: **Moderator Research Team Member:**

1) Participant Teachers and Their Disciplines: (also specify the school name)

2) Discussed Topics:

3) Results-Decisions:

APPENDIX C: Classroom Practice Form

Observer Name and Surname:

School:		
Teacher Name and Surname:		**Date of the Lesson:**
Class:	**Lesson:**	**Topic:**

1) Information about pre-lesson planning: (Pre-lesson developments, preparation, research, homework, etc.)

2) Lesson Observation:

Time	**Teaching:** (What teacher does is written in detail. Introduction, ApoKS, content of the lesson, etc. are expanded)	**Learning:** (Detailed actions and responses of students are written)	**Emphasis on focus of the month**

3) Post-lesson interview notes (acknowledgement, summarization of observation notes, and reminding to teachers related to their lessons):

APPENDIX D: STEM Lesson Plan Preparation Guide

Date: Lesson Subject: Topic:

Teacher: Class: Period: ....mins

1. Goal-Objectives :

1.1. Main discipline learning objective: 1.2. Other STEM discipline objective:

2. Materials:

3. Sources:

4. Authentic Problem of Knowledge Society (APoKS)

4.1. APoKS (Open-ended, more than one solution, 21st century life, association between product-process): 4.2. Limitations (Time, budget, used materials, eco-friendly, functionality or used information):

5. Content of the Lesson:

5.1. Engage (Engagement activity, story, and research):   5.2. Explore (About APoKS and limitations to generate an idea):   5.3. Explain (supporting the lesson by giving the necessary theoretical information)   5.4. Extend (Advanced research and/or theory – rigor in main discipline)   5.5. Evaluate (Presentation and sharing of products, evaluation rubrics)

APPENDIX E: Workshop Research-Record Book

Research- Record Book

1. Which information you may need?

2. Who is going to research? How is he/she going to research? How is he/she going to report it?

3. Research results:

Developing a Plan: Prototype/ Model/ Algorithm/ Data Collection Method

1) Which method you will develop for different plans? (brainstorming, finding the most nonsensical idea, propelling the impossible, discussions of ideas)

2) Who is going to record these different ideas into the idea pool, and how he/she will record?

3) Your Idea Pool:

4) Result: (Which plan are you going to implement?)