DEVELOPING TEACHER LEARNING PROGRESSIONS FOR K-12 ENGINEERING EDUCATION: TEACHERS' ATTITUDES AND THEIR UNDERSTANDING OF THE ENGINEERING DESIGN

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ABSTRACT

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Teachers at the K-12 level have a critical role in including engineering in their instruction. More teachers who are equipped with the knowledge and skills necessary to teach science using the engineering design process are needed. Aiming to build tools to measure and track the progress in teacher' attitudes and their understanding of the engineering design process suggested the use of learning progressions approach. The purpose of the study was to develop two teacher learning progressions for K-12 engineering education. The study followed design-based research with three phases of methodology framework; developing initial learning progressions, implementing a teacher professional development program, and refining the learning progressions. Data was collected from different groups of in-service science teachers. Data sources included written assessments, cognitive interviews, teacher logs, and clinical interviews. The analysis of data resulted in refined and empirically supported versions of the learning progressions. Implications and recommendations for future research were discussed in light of the findings and the relevant literature.

Keywords: Learning Progressions, K-12 Engineering Education, Professional Teacher Development

ÖZ

ÖĞRETMENLER İÇİN MÜHENDİSLİK EĞİTİMİ ÜZERİNE ÖĞRENME İLERLEMELERİ: ÖĞRETMENLERİN TUTUMLARI VE MÜHENDİSLİK TASARIM SÜRECİ KAVRAYIŞLARI

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Son yıllarda fen, teknoloji, mühendislik, ve matematik (FeTeMM) alanlarına anaokulundan 12. sınıfa kadar tüm eğitim düzeylerinde önem verildiği görülmektedir. Öğretmenlerin mühendislik eğitimine karşı olumlu tutumlarının ve kavrayışlarının sınıf içi pratiği etkileyeceğinden, öğretmenlerin hem tutum hem kavrayışlarının gelişimlerinin ölçülmesi ve izlenmesi vurgulanmalıdır. Öğrenme ilerlemeleri öncü bir yaklaşım olarak son yıllarda vurgulanmaktadır. Bu çalışmada mühendislik eğitimi konusunda öğretmenlerin tutumlarını ve kavrayışlarını ölçmek ve izlemek için dizayn-temelli yöntem ile öğrenme ilerlemeleri geliştirilmiştir. Veri toplama süreçleri veri analiz döngüleri şeklinde ilerlemiştir. Veri toplama süreci bilişsel görüşme, klinik görüşme, açık uçlu sorular ve çalışma kapsamında geliştirilen ölçek ile gerçekleşmiştir. Veri analiz döngüleri sonucunda öğrenme ilerlemelerinin üç farklı versiyonu ortaya konmuş ve literatür ışığında tartışılmıştır.

Anahtar Kelimeler: Öğrenme ilerlemeleri, FeTeMM Eğitimi, Mühendislik Tasarım Eğitimi

To all existential thinkers that embrace absurdity, anxiety, and their existence,
and to
SremmLife
Wyndham Hotel
Minerva Street
Kentpark
Akasya Caribou
THY
Regency Ballroom
Tomorrowland, and
flat white.

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LIST OF ABBREVIATIONS

LP	Learning Progressions
STEM	Science, Technology, Engineering, Mathematics
PD	Professional Development
EDP	Engineering Design Process
MoNE	Ministry of National Education
NGSS	Next Generation Science Standards
PLCs	Professional Learning Communities
OMC	Ordered Multiple Choice

CHAPTER 1

INTRODUCTION

1.1.Background to the Study

Large-scale attention has been given to the role of science, technology, engineering, and mathematics (STEM) in K-12 education in recent years (Capobianco & Rupp, 2014; Honey, Pearson, & Schweingruber, 2014; National Research Council (NRC), 2009). There is a widespread need for improving and increasing STEM skills among individuals to be able to thrive in the modern world (Afterschool Alliance, 2011). Raising students who can approach problems considering alternative perspectives, think systematically and creatively, and provide solutions with products necessitates a focus on STEM Education (MoNE, 2016). Efforts to encourage K-12 students to specialize in STEM fields (Page, Lewis, Autenrieth, & Butler-Purry, 2013) and to increase attention to STEM education for the enhancement of society (National Science Board, 2004) are critically important. Countries need a reformist STEM work-force to be competitive in the 21st century (Çorlu, Capraro, & Capraro, 2014). STEM pedagogy enables the improvement of 21st century skills such as innovation, creativity, collaboration, and critical thinking (NRC, 2012; Perry et al., 2008) by putting the development of science and engineering practices forward (NGSS Lead States, 2013). Engineering education has great potential to increase conceptual understanding of STEM disciplines while also increasing awareness of and interest in the role engineers play in advancing humanity (Brophy, Klein, Portsmore, & Rogers, 2008). Since teachers at the K-12 level have a critical role in including engineering in their instruction (Hsu, Cardella, & Purzer, 2010), more teachers that can teach science with engineering practices are needed (Capobianco & Rupp, 2014; Guzey, Moore, & Morse, 2016). Using science and engineering practices together as students learn the core disciplinary concepts; integration of engineering at the K-12 level is substantial. Engineering at K-12 schools can positively influence learning and achievement, recognition of nature of engineering and engineers, interest in engineering careers, and technological literacy (NRC, 2009).

The rationales introduced by Moore, Tank, Glancy, and Kersten (2015) to integrate engineering into K-12 education can be listed as: (1) engineering thinking helps with the development of students' 21st century skills, (2) engineering pedagogies have potential to increase student achievement in mathematics and science, and (3) engineering contexts can increase student interest in STEM disciplines and careers. The necessity for the integration of engineering to science education is highlighted in various current reports that guide educational practices and reforms as well: "Engineering in K-12 Education: Understanding the Status and Improving the Prospects" (NRC, 2009), "A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas" (NRC, 2012), "Next Generation Science Standards" (NGSS Lead States, 2013), and "Developing Assessments for the Next Generation Science Standards" (NRC, 2014). Predominantly underlined justifications in these reports for integrating engineering practices to K-12 level science education can be summarized as engaging students in scientific and engineering practices while making connections across different disciplines, offering innovative approaches to science instruction and assessment, enabling students to carefully consume scientific and technological knowledge, and engaging students in discussions on real-world issues. Although the goals of engineering and science differentiate, it can be concluded that the practices of science and engineering complete each other (Bybee, 2011) which underlined the critical contribution of engineering for K-12 science education.

The introduction of engineering to science instruction brings about a new content area with uncommon pedagogical approaches and practices such as the engineering design process, optimization, and modeling (Yoon, Diefes-Dux, & Strobel, 2013). With the introduction of such practices, science education at K-12 level should more actively include students with investigations where teachers use innovative techniques and activities (Bybee, 2011). Science teachers should be equipped with the knowledge and skills necessary to teach science using the engineering design process (Capobianco & Rupp, 2014), however inadequate teacher preparation is an obstacle that keeps the national standards from emphasizing the importance of engineering sufficiently (Fadali & Robinson, 2000). Teaching the teachers is one of the goals of extending engineering at the K-12 level where the other goals can be stated as increasing engineering enrolment and educating the future (Jeffers, Safferman, & Safferman, 2004). Encouraging and preparing science teachers are essential steps towards integrating engineering into classroom practice.

Helping teachers access the knowledge, skills, and dispositions to meet new educational standards can be accomplished with high-quality professional development (PD) opportunities (Capobianco & Rupp, 2014). Teacher PD programs elaborate on a main focus and several methods for teachers to enact that focus in their instruction (Kennedy, 2016). Teachers' participation to PD programs is closely linked to their classroom practice (Supovitz & Turner, 2000). According to Yoon et al. (2013), teacher PD programs are effective in increasing student classroom performance through teacher practice because PD programs contribute to teachers' content and pedagogical content knowledge, and to their attitudes toward the subject being taught. Recent teacher PD program efforts have made critical contributions to training science teachers to be K-12 STEM educators, however there has been less emphasis given to the teaching of engineering concepts in particular (Brophy et al., 2008). Improving teachers' attitudes and their understanding on engineering design process can positively impact the quality of classroom practice.

Teacher attitudes is one of the important factors in the success of new perspectives in education such as; implementing constructivist teaching and learning activities in classroom (Kasapoğlu, 2010), integrating computers to classroom practice (Zyad, 2016), and using internet applications (Chen, 2016). The integration of engineering to K-12 level instruction introduced a new subject area for teachers. This integration might be impacted by teachers' attitudes towards the engineering pedagogies that they are unfamiliar with (Lachapelle, Hertel, Shams, San Antonio, & Cunningham, 2014). It is substantial to have a clear picture of teachers' attitudes because negative teacher attitudes might serve as barriers to successful integration of engineering practices (Yoon et al., 2013). Since engineering design is an instructional approach to teach STEM content, teachers' gaining experience in engineering design can change their perspectives both towards engineering and towards STEM in general (Nadelson et al., 2013).

Teachers' understanding of the engineering design process is another factor important in the successful integration of engineering to science instruction. Teaching science with engineering design is not common among teachers (Guzey, Tank, Wang, Roehrig, & Moore, 2014) which might be because most teachers have little or no background on engineering (Lehman, Kim, & Harris, 2014). Teachers' knowledge about their content area and pedagogies are in connection with how their students develop deep understanding of engineering and with how their students develop interest in the field of engineering (Vessel, 2011). For students to have an understanding of and interest towards engineering, teachers' understanding of engineering is critical. In order to meet this need, PD programs for teachers are helpful contexts. Teachers participating to PD programs value the improvement in their knowledge of the engineering design process, engineering practices, and technology (Yoon et al., 2013). Teacher PD programs can help address the need for enhancing teachers' understanding of K-12 engineering education and in particular, the engineering design process.

Teacher PD programs on engineering education at the K-12 level are becoming more common. However, there are only a few reliable and valid measures developed to assess teacher progress (e.g. Lachapelle et al., 2014; Yaşar, Uysal, Robinson-Kurpius, Krause, & Roberts, 2006). Measuring and tracking teachers' improvement in K-12 engineering education is fundamental since invaluable feedback for teacher

development can be provided. Because integration of engineering to instruction and using engineering design in this integration is a very recent practice, efforts to properly measure teachers' attitudes and their understanding of the engineering design process can be effective starting points for teachers' professional improvement. Aiming to create tools to measure and understand; a) teachers' attitudes towards K-12 engineering education, and b) teachers' understanding of the engineering design process, suggested the use of learning progressions approach for the current study. In addition, the teacher PD program served as an instructional context where the learning progressions could be validated with collection and analysis of data.

Learning progressions research and practice provide reformist perspectives to science education with new perspectives on aligning curriculum, instruction, and assessment (Duncan & Hmelo-Silver, 2009). Learning progressions are descriptions of understanding that are in a certain order and that represent a framework for developing meaningful assessments (Alonzo & Steedle, 2009). With the creation of learning progression levels, the path that a learner goes through are documented based on relevant theoretical and empirical support. Learning progressions reveal "successively more sophisticated ways of knowing and thinking about ideas, evidence, claims and/or practices that deepen and broaden" (Duschl, Maeng, & Sezen, 2011, p. 131). The learner gains expertise along a continuum of levels that are identified based on theory and empirical evidence. The levels might range from basic understanding to complex understanding (Plummer & Krajcik, 2010; Songer, Kelcey, & Gotwals, 2009) or from low to high in case of a psychological construct such as attitude (Mahat, 2008; Nguyen & Griffin, 2013; Wilson, 2005). The learning progressions approach makes measuring and giving feedback processes more systematic and valid. In order to understand and measure the process that learners go through as they reach more advanced levels, assessment instruments are developed or teaching interventions are provided that are aligned with learning progressions levels (Duncan & Hmelo-Silver, 2009; Wilson,

2005) to empirically validate a learning progression. Learning progressions are research tools that offer a greater range and breadth of information to discriminate between distinct levels more reliably (Songer et al., 2009). Such information is helpful in aligning instruction, curriculum and assessment (Neumann, Viering, Boone, & Fischer, 2013).

The use of learning progressions approach for teacher development refers to both teachers' use of learning progressions to track and measure their students' thinking (Furtak & Heredia, 2014) and use of learning progressions to describe the progress in teacher related variables (Jin, Shin, Johnson, Kim, & Anderson, 2015; Schneider & Plasman, 2011; Windschitl, Thomopson, Braaten, & Stroupe, 2012). Although learning progressions currently have a wider usage for understanding K-12 students' progression (Alonzo & Steedle, 2009; Shea & Duncan, 2013; Smith, Wiser, Anderson, & Krajcik, 2006), learning progressions were also revealed to be useful for tracking the change in teachers' attitudes (Mahat, 2008; Nguyen & Griffin, 2012), teachers' knowledge (Jin et al., 2015), and teachers' practices in the classroom environment (Windschitl et al., 2012). Use of a learning progressions approach can extend the existing literature on the assessment of teacher development in K-12 engineering education by producing theoretically and empirically supported measurement tools.

1.2. Purpose of the Study

The current study aimed to propose two teacher learning progressions for K-12 engineering education, focusing particularly on teachers' attitudes and teachers' understanding based on the fact that science teachers' attitudes and understanding of K-12 engineering education can play critical roles in facilitating the integration of engineering to science instruction. The purposes of the current study in particular were to: a) develop a teacher learning progression to represent science teachers' attitudes towards K-12 engineering education and b) develop a teacher learning progression to represent science teachers' understanding of the engineering design process. Meeting the first goal of the study suggested the development of a survey to validate the learning progression on teacher attitudes. This survey was *not* developed to understand the difference in teachers' attitudes before and after participation to a certain program or a treatment within the scope of the current study. Such usage can be achieved with final versions of the learning progression and the survey with future studies. The goal was to develop the first initial and working version of a survey that is theoretically and empirically aligned with the learning progression on attitudes. Revealing a progress in teachers' attitudes and understanding was not in the scope of the current study. With the goals outlined, the research questions that guided the study were:

1. How can science teachers' attitudes towards K-12 engineering education be depicted with a learning progression?

   1.a. How can a survey on science teachers' attitudes towards K-12 engineering education be developed to validate the learning progression?

2. What levels do science teachers typically experience as they move from a novice to a more sophisticated understanding of the engineering design process?

1.3. Significance of the Study

A major goal for K-12 engineering education is about making tone of the disciplines of STEM education; engineering more apparent (Bybee, 2009). STEM programs and projects typically involve the opportunity for teachers to help their students develop 21st century skills (Bybee, 2010). The vision for STEM 2026 included six interconnected components for integration of STEM education (U. S. Department of Education, 2016). Among these components, three of them were directly addressed in the goals of this study. These three components were to provide; a) educational activities that contain play and risk, b) learning experiences with approaches to solve challenges, and c) innovative and accessible measures of learning. The first two components were included with the learning experiences on engineering design that were provided to teachers through a teacher PD program. For the third component, the learning progressions served as the innovative tools that can accurately document teachers' progress in their attitudes towards K-12 engineering education and their understanding of the engineering design process.

Typically learning progression development efforts make use of large sample sizes such as; 342 sixth to twelve grade students (Mayes et al., 2014), 939 students and 23 teachers (Songer & Gotwals, 2012), and 2688 students and 29 teachers (Lee & Liu, 2010). To continue, the example studies on learning progressions development either used large sample sizes (Duncan et al., 2016; Todd & Kenyon, 2015) or conducted more than one cycle of data collection and analysis. These addressed the fact that developing and validating learning progressions requires great effort and the process might take a long period of time with the inclusion of multiple data sources and data collection tools. This situation was considered as a strength of the current study in that data was collected from different groups of teachers with the usage of various data collection tools. Another noteworthy point was that the literature did not provide any learning progressions developed in the national context. The current study can be considered as a first attempt to introduce a learning progression to its national context.

A majority of studies in learning progression literature, focused on student learning and progression (Alonzo & Steedle, 2009; Duncan, Rogat, & Yarden, 2009; Gunckel, Covitt, Salinas, & Anderson, 2012; Parker, Elizabeth, & Anderson, 2015), however there are emerging examples of learning progressions for teacher development (Furtak, Thompson, Braaten, & Windschitl, 2012; Jin et al., 2015). Although learning progressions have been proposed to further investigate student thinking, they can also lead the way in understanding how teachers' knowledge progresses in time (Schneider & Plasman, 2011). Teacher development is one of the five potential uses of learning progressions (Kobrin, Larson, Cromwell, & Garza, 2015). In terms of content, there was found to be a focus on student learning progressions for engineering practices such as scientific argumentation (Berland & McNeill, 2010), but there are no learning progressions developed for engineering practices, engineering design, or attitudes towards K-12 engineering education.

Developing learning progressions is a promising approach towards tracking progress in terms of the variable of interest. With this approach and through the existence of empirically generated levels, valid inferences on the location of the respondents can be gained (Wilson, 2009). Learning progressions suggest the idea of moving from a point to another, calling for a direction towards greater expertise (Gotwals & Alonzo, 2012; Stevens, Delgado, & Krajcik, 2010). Additional distinguishing features of learning progressions can be stated as "being developed and refined with existing research, being developed hand in hand with well-designed assessments" (Hess, 2008, p. 3).

Learning progressions approach served as the key principle to organize the main curricular structure for K-12 science education (NRC, 2012). Formerly, curriculum and the instructional materials were designed with the notion that what students should learn is a simpler version of what experts know (Lehrer & Schauble, 2015). This form of thought was challenged by the developmental view that documents learning in its complexity. Learning progressions can be used in planning learning materials that can enhance understanding and provide opportunities for monitoring the learners with appropriate assessment within and different levels of K-12 education (Duncan et al., 2009). Learning progressions can serve as main scheme for generating curriculum units, assessment instruments, and professional development programs (Songer & Gotwals, 2012). Carefully designed contexts for learners enable them to reach goals they might not have been able to reach otherwise. Lastly, learning progressions research draw attention to a collaborative approach; researchers and educators working together to refine tools (Hess & Kearns, 2011). These can be interpreted as major innovations to support measurement of progression and the alignment between instruction, measurement, and curriculum.

The fact that learning progressions are created with theoretical and empirical support together is a critical distinction from traditional methods (Wilson, 2005). The articulation of especially the intermediate levels, that were referred to as *messy* *middles* (Gotwals & Songer, 2013), provide a more valid interpretation of the respondents on the variable that is being measured. Measuring location along a continuum is opposed to choosing sequences of disconnected topics solely based on analyzing what the current literature present (Corcoran, Mosher, & Rogat, 2009). Learning progressions approach can bring about a new perspective to investigating progress, providing feedback, and to anticipating difficulties (Breslyn, McGinnis, McDonald, & Hestness, 2016). The movement towards higher levels of the learning progression can be studied within the duration of an instruction context. “Instruction-assisted learning progressions” (Jin et al., 2015, p. 1270) refers to progress following a guiding instructional context. Such learning progressions are important in defining paths to be taken in an instructional context which means the curriculum, instruction, and assessments can be systematically aligned (Jin et al., 2015). Teacher PD programs can serve as instructional contexts where learning progression can be validated. For the current study, different strategies for the refinement and validation of the learning progressions were followed; developing an associated survey along with the learning progression on teacher attitudes, conducting Rasch analysis with survey data, collection and analysis of qualitative data, and use of an instructional context; a teacher PD program.

The introduction of engineering concepts and practices at the K-12 level brings about many opportunities as well as challenges regarding teachers’ knowledge and their professional development (Brophy et al., 2008). Integration of engineering to science instruction is quite complicated which necessitates quality professional development of science teachers (Guzey et al., 2014). There should be more opportunities for PD programs that can engage teachers in engineering design activities (Donna, 2012; Hynes & Santos, 2007) since these programs are effective methods for preparing teachers to teach engineering. An influential factor to make engineering education successful at the K-12 levels is to make sure teachers understand the basic engineering concepts and they are comfortable as they engage their students in engineering activities (NRC, 2009). The literature contained examples of systematic rubrics and examinations to evaluate teachers' understanding of the engineering design process (Bailey & Szabo, 2007; Duncan, Diefex-Dux, & Gentry, 2011) and teachers' engineering design performances (Wendell, 2014). At this point, the current study addressed the need to extend the literature by introducing learning progressions that can be thought of as theoretically and empirically validated versions of rubrics. Developing learning progressions for teacher development is a recent practice yet requires vital importance (Furtak & Heredia, 2014). With the fact that learning progressions are empirically supported and aligned with assessment and instruction (Duncan & Hmelo-Silver, 2009), learning progressions can offer an innovative perspective for teacher development on K-12 engineering education.

The current study contributes to the emerging learning progressions literature on teacher development and monitoring teacher progress. A critical point was also to support the learning progressions literature on areas that no learning progressions were developed before. The literature did not include examples of teacher learning progressions on engineering design and K-12 engineering education.

There were several aspects on weaknesses of teacher PD programs in general the the current study addressed. Some of these aspects can be listed as insufficient professional trainers, lack of collaboration between teachers, and insufficient feedback to the participant teachers and lack of systematic training models; building a community during the PD where teachers can discuss concept, skills, and issues, having a match between strategies and purposes of the PD, need for more teacher PD programs on engineering content, or relevant pedagogical approaches, and teachers' having requirement to participate to the PD program (Bayrakçı, 2009; Hynes & Santos, 2007; Kennedy, 2006; Lee, 2005). For the last aspect, the teachers were all volunteers to participate to the PD program which affected their motivation to learn positively. For insufficient systematic training models, teacher PD program delivered in the current study was based on a conceptual framework which was developed by the researchers based on findings of the literature. To continue, the teacher PD program focused on engineering design challenges and activities where teachers collaborated to work on the engineering design process and where they presented their final designs again collaboratively. So teachers built a community where they learnt together. The PD program having trainers some of whom were faculty members on engineering and some of whom were faculty members on educational sciences contributed to the quality of professional trainers.

Another point of attention for teacher PD programs to improve is to use learning theories to support teachers' growth because the growth process is complex (Clarke & Hollingsworth, 2002). The critical importance of gaining proofs of teachers' learning and effective professional development during a PD program was highlighted by Borko (2004) as well. Investigation of teacher knowledge at the beginning and monitoring the changes in the knowledge are major points for teacher PD programs (Van Driel, Beijaard, & Verloop, 2001). Many teacher PD programs fail to document the process of teacher change sufficiently (Guskey, 2002). These points of concern were addressed with learning progressions approach that support learning and assessment (Corcoran et al., 2009).

Understanding the possible paths of teachers' attitudes towards K-12 engineering education, and teachers' understanding of engineering design process are critically important in introducing engineering to K-12 settings. The findings and the products of the current study can facilitate the integration of K-12 engineering education to science instruction and can improve science teacher development.

1.4. Definition of Terms

Attitude: "An evaluation of an object of thought. Attitude objects comprise anything a person may hold in mind, ranging from the mundane to the abstract, including things, people, groups, and ideas" (Bohner & Dickel, 2011, p. 392).

Construct maps: “A well thought out and researched ordering of qualitatively different levels of performance focusing on one characteristic.” (Wilson, 2009, p. 718).

Engineering: “Engagement in a systematic practice of design to achieve solutions to particular human problems” (NRC, 2012, p. 11-12).

Engineering design process: “Engineers design and build all types of structures, systems and products that are important in our everyday lives. The engineering design process is a series of steps that engineering teams use to guide them as they solve problems” (Tayal, 2013, p. 1).

K-12 engineering education: Three general principles for K-12 education are: “(1) K-12 engineering education should emphasize engineering design; (2) K-12 engineering education should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills, and (3) K-12 engineering education should promote engineering habits of mind” (NRC, 2009, p. 4).

Learning progressions: “Descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time” (NRC, 2007, p. 217).

Teacher learning progressions: “Teachers move from initial experiences with learners in their pre-service programs to (perhaps) induction programs for new teachers to professional development programs for continuing teachers.” (Schneider & Plasman, 2011, p. 534).

Understanding: “Understanding develops over time………If mastery of a core idea in a science discipline is the ultimate educational destination, then well-designed learning progressions provide a map of the routes that can be taken to reach that destination.” (NRC, 2011, p. 26).

CHAPTER 2

LITERATURE REVIEW

2.1. Emergence of K-12 Engineering Education

STEM education is mostly interpreted as science and mathematics and technology and engineering disciplines are not sufficiently emphasized (Bybee, 2010). In order to raise students who can meet the challenges of the future society, there is a connection addressed between engineering and K-12 education (NRC, 2012). Science and mathematics as curriculum areas, have gone through many changes recently following Common Core State Standards (Common Core State Standards Initiative, 2010), STEM approach, and the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). The framework; NGSS (NGSS Lead States, 2013), addressed the connection between engineering and other content areas such as mathematics, science and technology (Quinn, Schweingruber, & Keller, 2012). The framework highlighted K-12 education to be built around three dimensions: (1) scientific and engineering practices, (2) crosscutting concepts that unify science and engineering, and (3) core ideas from the disciplinary areas of physical science, life science, earth/space science, and engineering (NGSS Lead States, 2013). A distinguishing attribute of the NGSS was the integration of engineering and technology into science education by emphasizing engineering and technology more then before and giving more attention to engineering design (NGSS Lead States, 2013). With the introduction of NGSS, teachers need to be competent on teaching elements of engineering in their classrooms (Goodale, 2013) since the new standards includes engineering from kindergarten to 12th grade level.

Engineering is a field of applied science focusing on engineering design; an iterative process followed to design or solve a problem considering certain constraints (Vessel, 2011). Activities that focus on engineering design at the K-12 level is beneficial by offering opportunities to students such as developing 21st century skills, making connection to other STEM subjects, and learning about careers in engineering (Bybee, 2010). However, engineering is rarely considered a separate content area at the K-12 level partly because there are no agreed-upon standards on how to integrate engineering to the K-12 curriculum. As engineering was revealed to be pedagogically effective for developing students' skills, it became important to address the context of such learning. Engineering is not a separate school discipline yet (Vessel, 2011) and there is not a clear definition or methods on how to enact engineering at the K-12 level most effectively (Moore et al., 2014b). Currently, there is not a consistent framework for understanding and implementing engineering design into K-12 level education as there is a variety of engineering design models and explanations. However, there are continuous efforts to ensure a place for engineering in K-12 settings.

The increasing focus on integrating engineering to K-12 education can be considered as an essential step towards the change in classroom practice (Moore et al., 2015). Currently, engineering is introduced to K-12 settings mostly through informal learning environments; after-school programs and summer programs (NRC, 2009). For the formal classroom setting, there are two main approaches followed at the K-12 level; 1) adopting a complete engineering curriculum, or 2) integrating selected curriculum resources into other subject areas such as science or mathematics. The first approach: "*adopting a complete engineering/technology education curriculum";* introduces engineering as a separate subject whereas the second approach is the integration of engineering concepts and applications (Kimmel, Carpinelli, Burr-Alexander, & Rockland 2006). Considered with more detail, for this first approach, engineering serves as the primary organizer for student learning. Examples of this can be listed as the initiatives; Project Lead the Way, The Infinity, and lastly Engineering the Future. For the state level, standards by the Massachusetts Department of Education was the first attempt to develop set of content standards for a K-12 curriculum (Massachusetts Department of Education, 2006). These standards present a model for other states in USA and for other parts of the world that are interested in having explicit standards for engineering (Brophy et al., 2008). To summarize, in this approach, engineering exists as a stand-alone course and engineering is the main organizer for student learning.

For the second approach "*integrating engineering into the curriculum"* (Kimmel et al., 2006), engineering serves as a tool for teaching science and mathematics (Cunningham, Knight, Carlsen, & Kelly, 2007). Engineering and concepts and skills are used in other subjects such as science, mathematics, or technology. For this approach, two curriculum integration models were introduced by Moore, Stohlmann, Wang, Tank, and Roehrig (2014). For the *content integration*, understanding in multiple STEM disciplines is developed with help of one motivating context. The focus is on multiple STEM disciplines, not only on one. Merging multiple STEM content in one single curricular activity to have a focus of main concepts and perspectives from different disciplines is prominent. Whereas for the *context integration;* understanding in one STEM discipline is developed with help of contexts from other disciplines. The main focus is on only one discipline and uses the contexts of other disciplines to make content more relevant (Moore et al., 2014a). The current study adopted the *context integration model* where understanding in engineering was the main focus. This was supported by the other three disciplines; science, technology, and mathematics within engineering design activities. Science and engineering content knowledge can be integrated and implemented in the classroom through engineering design as a focus (Quinn et al., 2012). According to Milano (2013), "In the next generation of elementary classrooms, students are actively engaged in the practices of science and engineering, using design as a vehicle to build and revise knowledge of key disciplinary core ideas" (p.10).

Engineering design challenges provide the experiences to learners to solve grand challenges that can be at the community, national or global levels (U. S. Department of Education, 2016). Although there are other models and explanations on engineering design, two sources were more commonly used to understand the engineering design process. According to the first source; "A framework for K-12 science education: Practices, crosscutting concepts, and core ideas" (NRC, 2012)*;* engineering design process is based on three component ideas: "a) defining and delimiting engineering problems, b) designing solutions to engineering problems, and c) optimizing the design solution" (NRC, 2012, p. 203). These component ideas are not linear and they follow each other in circles; the process is iterative and flexible. This enables the designer to go back to other stages and make revisions. This is a significant distinction between engineering design process and scientific inquiry (NRC, 2012). The second source is the recently developed framework by Moore et al. (2014b) which presented elements that should be included in a quality K-12 engineering education program. The authors systematically reviewed prominent reports, and standard documents to generate the key indicators of a quality K-12 engineering education. Among these elements, the engineering design process was identified with three key indicators; "a) problem and background, b) plan and implement, and c) test and evaluate" (Moore et al., 2014b, p. 9). Overall, both sources on the engineering design process were noticed to include similar descriptions which were combined and expressed together in Table 1. The combination of the descriptions in these sources in Table 1 served as a guide in; a) understanding the engineering design process, b) structuring the professional development program content, and c) developing a learning progression on engineering design understanding.

When it comes to the features of the engineering design process in more detail, the educational literature identified four common core features, "(1) the design process begins with problem definition, (2) design problems have many possible solutions and engineers must find systematic approaches to choosing between these, (3) design requires modeling and analysis, and (4) the design process is iterative" (Berland, Steingut, & Ko, 2014, p. 706).

Table 1. *Descriptions on Engineering Design Process*

Component ideas of the engineering design cycle (NRC, 2012, p. 203)	Descriptions	Key indicators of engineering design process (Moore et al., 2014b, p.9)
Define and delimit engineering problems	"Stating the problem to be solved as clearly as possible in terms of criteria for success, and constraints or limits Researching the problem, participating in learning activities to gain necessary background knowledge" (Moore et al., 2014b, p.9; NRC, 2012, p. 203)	Problem and background
Design solutions to engineering problems	"Begins with generating a number of different possible solutions, then evaluating potential solutions to see which ones best meet the criteria and constraints of the problem." "Judging the relative importance of different constraints and trade-offs. Mostly concludes with creation of a prototype, model, or other product." (Moore et al., 2014b, p.9; NRC, 2012, p. 203)	Plan and implement
Optimize the design solution	"Solutions are systematically tested and refined and the final design is improved by trading off less important features for those that are more important." "Use test result feedback in redesign. Because of the iterative nature of design, students should be encouraged to consider all aspects of a design process multiple times in order to improve the solution or product until it meets the design criteria." (Moore et al., 2014b, p.9; NRC, 2012, p. 203)	Test and evaluate

In investigating teachers' understanding of the engineering design process and its features, these four common core features can be accepted as sign of a more sophisticated understanding.

Several model were located in the literature for engineering design process and its steps. These models can be considered as more detailed descriptions of the engineering design process steps that were briefly provided in Table 1. The two most useful and commonly used engineering design process models with descriptions of the steps to follow can be reported as the five-step model by Museum of Science (Cunningham, 2009) and the eight-step model by Massachusetts Engineering Framework (Hynes et al., 2011, p. 9). In the first model, there are five steps of the engineering design process: “a) ask, b) imagine, c) plan, d) create, and e) improve” (Cunningham, 2009, p. 14). The model is in a cyclical format as typical engineering design process models. This cyclical depiction can be explained by the iterative nature of the engineering design process. As new problems arise, there occurs a need to revisit the steps and refine the product. The design work can be expressed as a set of steps that are developmental, structured, and iterative (Asunda & Hill, 2007). The engineering design process is cyclical where revisions may lead the process to a further analysis or synthesis (Hynes, 2012). The first step includes what the problem is and trying to find answers for the question what has been done so far. The second step addresses brainstorming on possible solutions followed by choosing the best solution. The next step; plan includes drawing a diagram or a sketch and laying out the materials needed. The next step refers to building the design and testing it. The final step is on revisions to make the design better. This engineering design process model is very useful especially for introducing the engineering design process to a more novice audience. However, to lay out the possible levels between a novice understanding and a more sophisticated understanding of the engineering design process, a comprehensive model might be needed. The eight-step engineering design process model by Massachusetts Department of Education (Hynes et al., 2011) is influential in addressing this need. This model was provided in Figure 1.

There are more number of steps to complete the engineering design process in this model which basically makes it a more detailed version of the five-step model. The first step is the identification of the need or the problem by brainstorming on the criteria and constraints as well. The second step researching about the need or the problem. This step includes a thorough research of the problem which might include scanning books, journals, internet databases, videos, and consulting people who might have knowledge. The third step is developing possible solutions. This step is critical in deciding on the best solution possible which is the fourth step. While deciding on the best possible

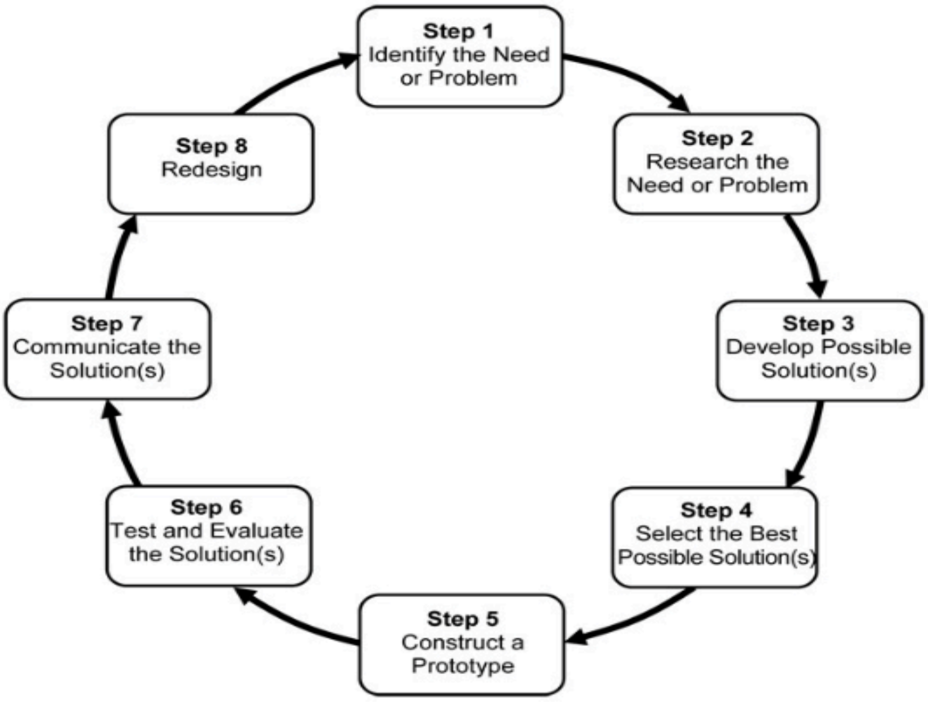


Figure 1. Engineering design process model

solution, criteria and constrains are carefully revisited and discussed, and a tradeoff strategy is utilized. In the fifth step a prototype is created where the plan is documented with a drawing or a model. The sixth step focuses on testing an evaluating solution. The design is subject to a test in this step where taking and reporting data is critical. In the seventh step the solutions are communicated. This is basically reporting the results and areas for improvement. In the eighth and the final step, a redesign starts where improvements are put into practice.

The two engineering design process explanations presented together with Table 1, and the engineering design process model in Figure 1 were the main driving forces in understanding what a sophisticated understanding of the engineering design process might include. The two models had guiding roles in describing what constitutes an engineering design model. To summarize, these sources are critically important in creating an upper anchor (Breslyn et al., 2016); highest level of understanding of the learning progression on engineering design process.

Engineering design quickly appeals to students who could struggle in traditional science classrooms (Cunningham et al., 2007). Students are engaged in rich learning opportunities with the benefits of design and troubleshooting (Brophy et al., 2008). By exposure to engineering design, students can comprehend that engineering involves creating things to enhance the society, which is critical for a diverse population (Carlson & Sullivan, 2004). Wicklein (2006) put forth that engineering design provides a sound framework for organizing curriculum and that it is an ideal platform to integrate mathematics, science, and technology. Attracting students to engineering related professions can be challenging due to engineering not being a separate teaching subject (Nugent, Kunz, Rilett, & Jones, 2010). However, students' experiences with engineering design can enhance their understanding of engineering and motivate them in science and engineering careers (Bybee, 2009). Students grasp science and mathematics concepts and retain them better with engineering design problems that provide a real-world context (NRC, 2009). The engineering design process and the engineering design challenges can serve as contexts for learners to understand engineering design process along with concepts related to science, mathematics, and technology.

2.2. STEM and K-12 Engineering Education in Turkish Context

Recently many educational initiatives have put great emphasis on integration of STEM in K-12 classrooms in Turkey. STEM Education Turkey Report (Akgündüz et al., 2015), and STEM Education Report (MoNE, 2016) aimed to create an awareness on STEM education and to prepare educational programs on STEM particular to Turkish context. Because there is a decrease in the number of high ranking students who choose a career in STEM fields between 2000 and 2004, the need for STEM work force might be influenced (Akgündüz, 2016).

In Turkey, there are efforts to implement STEM activities in K-12 contexts. As a fundamental guide and an example from the international context, “The Next Generation Science Standards” (NGSS Lead States, 2013) is organized in a particular way so that all STEM disciplines are integrated. This can help students comprehend the relevance of science, technology, engineering, and mathematics in real life. The engineering design process is clearly emphasized and mentioned at all grade levels (NGSS Lead States, 2013). In Turkey there are similar efforts where K-12 students identify and work on problems that address the four disciplines and where they follow the engineering design process. The Technology and Design course for the 7^{th} and 8^{th} grades is an example where engineering design process is typically followed. Literature also revealed other practice efforts such as participation to short-term STEM activities and projects for K-12 students (Gencer, 2017; Karahan, Canbazoğlu-Bilici, & Ünal, 2015; Yamak, Bulut, & Dündar, 2014) where the engineering design process is elaborated on. When the new draft science program is examined that was shared in early 2017, one of the main goals is clearly to integrate engineering concepts and engineering design process as a method to science education. These examples underlined the need to integrate engineering concepts and practices to science education.

The Scientific and Technological Research Council of Turkey has a significant role in providing support to STEM approach with projects for K-12 students (Çolakoğlu, 2016). Exposure to STEM activities were found to contribute to students’ academic achievement (Ercan & Şahin, 2015) and to their skills development (Baran, Canbazoğlu-Bilici, Mesutoğlu, & Ocak, 2016). A need for Turkey was revealed to be a focus on STEM education programs for gifted students at K-12 levels (Kanlı & Özyaprak, 2016).

Studies in Turkish context most commonly worked on developing instruments (Buyruk & Korkmaz, 2014) and on adapting existing instruments to Turkish (Yıldırım & Selvi, 2015) to collect data useful for improving STEM education. In the training programs for pre-service and in-service teachers, major data collection methods were questionnaires (Altan & Ercan, 2016; Çınar, Pırasa, Uzun, & Erenler, 2016; Gül & Marulcu, 2014), interviews (Altan, Yamak, & Kırıkkaya, 2016) and drawings (Gül & Marulcu, 2014). In order to advance the measurement methodologies further and to introduce assessment tools that are based on empirical findings, learning progressions can provide an alternative perspective. Learning progressions can show movement towards higher levels from lower levels of the variable of interest with use of existing research findings and empirical data (Duncan & Hmelo-Silver, 2009; Hess, 2008).

In Turkey, there was found to be a larger effort towards understanding pre-service teachers' perceptions or perspectives on STEM education and engineering (Akaygün & Aslan-Tutak, 2016; Altan & Ercan, 2016; Marulcu & Sungur, 2015) also through workshops and other education programs (Altan et al., 2016). Improvement of teachers on STEM education is one of the broad strategies that should be highlighted in order to integrate STEM education successfully. The other strategies can be listed as: a) more empirical research on STEM education, b) revising curriculum to include STEM education carefully, and c) providing necessary materials to schools (MoNE, 2016). Although teachers are motivated to implement engineering activities in their classrooms (Hacıoğlu, Yamak, & Kavak, 2016), barriers teachers face can be aversive in their adoption of a particular strategy (Blackwell, Lauricella, Wartella, Robb, & Schomburg, 2013).

For in-service teachers, there are only recent efforts to expose them to engineering through teacher PD programs on STEM Education (Sungur, 2013). There is limited research on in-service teachers' professional development on engineering concepts and practices. However, it is critical for teachers to make connections between their field of expertise and other disciplines, to discuss STEM careers, and to include design activities in their classes (Gülhan & Şahin, 2016). In-service teachers having expertise solely in their field of expertise cannot be sufficient for raising human potential that the country needs (Çorlu et al., 2014). Because the teacher PD programs are positively influential on teachers' views of STEM education (Altan & Ercan, 2016), such contexts can be useful for promoting STEM in the country.

The most recent science curriculum in Turkey (MoNE, 2013) did not have a certain focus on integration of STEM or engineering practices. However, the new draft middle school science curriculum introduced by the Ministry of Education in early 2017 (MoNE, 2017), was noticed to include a full unit on engineering concepts and engineering design principles from grade level four to grade level eight. Students' improvement in engineering and design skills, understanding of interdisciplinary interactions, application of their knowledge through designs, and products were some of the underlined aspects of this draft science curriculum. This innovation for Turkish science education currently necessitates the professional development of teachers on engineering concepts and practices.

For Turkey, STEM education is a necessity without a doubt however exposing each and every student to STEM education is a very challenging endeavor (Akgündüz et al., 2015). STEM in Turkish context can be considered as being shaped both by teachers' and students' interests and experiences. The successful implementation of STEM integration in Turkish context is effected by school level and type and the characteristics of STEM teachers as well (Çorlu et al., 2014). Future research can pay attention to the needs and specifications of various factors such as location, regional, and sociological needs (Kanlı & Özyaprak, 2016). Still for all schools in Turkey, STEM education should be of primary interest (MoNE, 2016). STEM activities should not be limited to formal school environments but concentrate on solving real life problems as well (Akgündüz et al., 2015). In order to improve in international examinations; TIMSS and PISA, conducting more research, and improving in-service teachers need to be considered among the important recommendations for the successful integration of STEM for the Turkish context (Akgündüz et al., 2015). In the Turkish context, lack of teachers, the disconnect between teacher education programs and real settings of the schools has always been among the issues teacher education system faced in time (Çakıroğlu & Çakıroğlu, 2003). One critical recommendation in terms of transforming teacher education can be exposing pre-service teachers to more opportunities where they can learn more about integrated teaching and where they can practice integrated teaching (Çorlu et al., 2014). Thinking like an engineer should be more emphasized so that individuals can be raised as responsible of their own learning (Cavaş, Bulut, Holbrook, & Rannikmae, 2013). For Turkish context, some of the further critical points of consideration for future research can be listed as conducting comparison studies with different populations and grade levels, integration of STEM education to the programs, and increasing focus on interdisciplinary integration (Gülhan & Şahin, 2016).

Extending the above findings, some of the areas for improvement for teacher PD programs in the Turkish context can be reported as insufficient professional trainers, lack of collaboration between teachers, insufficient feedback to the participant teachers (Bayrakçı, 2009), the need for increasing number of programs to include follow-up sections where teachers can gain and reflect on experience in real classroom context and where teachers can be monitored successfully (Avery & Reeve, 2013; Nadelson et al., 2015) as such programs can result in permanent changes in teacher knowledge (Van Driel et al., 2001), and advancing techniques for measuring participant teacher progress that are mostly limited to adapted versions of questionnaires. Other than that, the number of teacher PD programs on engineering practices and STEM education needs to be increased. Insufficient in-service teacher training programs serve as barriers in integration of new approaches to classroom practice by teachers (Göktaş, Yıldırım, & Yıldırım, 2009). Since resources in terms of money, energy, and time are spent on the design and delivery of in-service teacher PD programs (Kennedy, 2016), addressing their insufficiencies and putting efforts to improve them are of vital importance.

It can be concluded that future reforms in teacher education in the national context, universities can have a critical influence in raising teachers who can integrate different STEM disciplines in their instruction once they start working in schools. Another point of focus should be teacher PD programs for in-service teachers on STEM and K-12 engineering education.

2.3. Teachers' Attitudes towards K-12 Engineering Education

Attitude can be defined as the personal evaluation of a particular object a person holds in mind which might include but not limited to ideas and things (Bohner & Dickel, 2011). Attitudes are enduring, learned and related to behavior (Shrigley, Koballa, & Simpson, 1988). Sub-concepts within attitude might contain perceptions (Iskander, Kapila, & Kriftcher, 2010), confidence (Hynes & Santos, 2007), and comfort (Diefes-Dux, 2015).

When it comes to teachers' attitudes there might be different aspects related such as teachers' attitudes towards teaching their subject matter and their attitudes towards their field of expertise in general (Van Aalderen-Smeets & Van Der Molen, 2015). Change in teachers' attitudes generally takes places after teachers observe improvements in students' learning process (Guskey, 2002). As teachers observe effect on student learning and on other student outcomes, their overall beliefs and attitudes are shaped. This point was elaborated in the attitude change model by Kelman (1958) that focused on how change occurs in attitudes. This model was composed of three stages to explain the change in attitudes; 1) compliance, 2) identification, and 3) internalization. According to the model, as the positive attitude is observed, the object of attention is intrinsically rewarding for the individual and it is in line with the existing value system. Positive attitude signifies usefulness in the thinking process of the individual. At the lack of positive attitude, what matters is the existence of an influencing agent where the object of attention is only externally rewarding (Kelman, 1958). When teachers gain more experience in classroom with their students, their attitudes are being shaped. Changes in teachers' behavior is effective in shaping teachers' attitudes (Hew & Cheung, 2014). Teacher attitudes was found to be an important element in the success of students' improvement both for their attitudes towards teaching and their attitudes towards their field in general. Teachers' attitudes towards a certain subject matter and how teachers present it in their classrooms are critically important in understanding the success of teaching and learning experiences (Zacharia, 2003). Some of the possible outcomes that are influenced by teachers' attitudes are students' academic achievement (Palardy & Rumberger, 2008), students' personalities and life performances (Uluğ, Özden, & Eryılmaz, 2011), teachers' classroom practices (Sharma & Sokal, 2015), teachers' judgement of students (Glock, Beverborg, & Müller, 2016), teacher self-efficacy (Carleton, Fitch, & Krockover, 2007), and teaching style (Karamustafaoğlu, Çakır, & Celep, 2015). Teachers' attitudes are closely linked to their beliefs and practices in understanding and advancing educational processes. These findings demonstrated the prominence of teachers' attitudes.

Teachers' role in guiding students' career choices and positive attitudes towards engineering is in line with how they promote engineering as a profession (Lindsley & Burrows, 2007). It is important for teachers to have a positive attitude towards improving themselves in K-12 engineering education themselves. Some of the factors for teachers' resistance in improving themselves in engineering practices were found to be; teachers not feeling that the students are capable of being motivated towards engineering activities (Van Haneghan, Pruet, Neal-Waltman, & Harlan, 2015), overall negative attitudes towards engineering (Yoon et al., 2013), insufficient administrative support, incompetency and insufficient knowledge, problems faced during pre-service education and finally insufficient time to learn about design, engineering and technology (Yaşar et al., 2006). Teacher PD programs are important contexts to reinforce and refine attitudes (Collinson, 2012) that can highlight factors of resistance. For K-12 engineering education, PD programs were revealed to have a role in increasing teachers' positive attitudes towards components such as general impressions of engineering, importance of engineering and/or engineers, and teaching engineering curricula (Lachapelle et al., 2014; Lindsley & Burrows, 2007). Teachers were shown to have positive attitudes towards design, engineering and technology (Yaşar et al., 2006) however for teachers to increase positive attitudes, exposure to PD programs can be effective.

An understanding of teacher attitudes is significant for planning teacher education programs both at the pre-service and the in-service levels. With exposure to professional development opportunities, teachers can enhance their self-efficacy and they may start feeling less dependent on contextual factors (Van Aalderen-Smeets & Van Der Molen, 2015). Teachers' attitudes were found to increase positively towards various variables following participation to PD programs. Some example were attitudes towards interdisciplinary teaching in STEM subjects (Al Salami, Makela, & de Miranda, 2015) and teachers' attitudes towards subject they teach (Smith, 2015; Yoon et al., 2013). Because the literature needs more findings on science teachers' uncertainty to implement engineering activities (Capobianco, Diefes-Dux, Mena, & Weller, 2011) research on PD programs and teacher' attitudes can be highly useful. The need for examination of contributions of PD programs for in-service teachers is valid for both the national and the international contexts.

The literature included examples of developed learning progressions on teacher attitudes with their associated instruments; Mahat (2008), and Nguyen and Griffin (2012). The authors of these two studies labeled their learning progression as a construct map based on basically following the construct modeling measurement framework (Wilson, 2005) in developing and analyzing their learning progression. It might also be the case that, since construct maps are smaller and simpler versions of learning progressions, they are labeled as so. These arguements were critical in how the learning progression is named however, the label *learning progression* can be preferred which is a broader category for such products.

It is important to primarily have knowledge on teachers' attitudes since teachers are expected to implement engineering activities in their classrooms. This requires research and practice efforts towards both measuring attitudes reliably and validly and developing positive teacher attitudes towards K-12 engineering education. For measuring teachers' attitudes, only one instrument was located in the literature that specifically assesses teachers' attitudes towards K-12 engineering education; "Teacher Attitude Survey (TAS)" (Lachapelle et al., 2014). Most accessed instruments measured teachers' attitudes toward science or math (Lachapelle et al., 2014). This addressed the need for more instruments that can accurately measure and document teachers' attitudes towards K-12 engineering education. It is critically significant to present psychometrically sound instruments to the literature that can help researchers, and policy makers gain information on teacher attitudes towards K-12 engineering education. Developing a learning progression on attitudes with its associated instrument can address this need as well as serve to validate the learning progression.

2.4. Teachers' Understanding of the Engineering Design

It is becoming more common to integrate engineering to K-12 teaching with learning standards necessitating a particular focus on engineering design (Hsu et al., 2010). Integrating engineering design to K-12 education is substantial to reach some of the important goals of engineering education; a) enabling students to learn concepts in a motivating context and b) introducing the engineering discipline to the students (Berland et al., 2014). When students are provided with a foundation in engineering design, they are better equipped to solve major problems related to society they will face in their future lives (NGSS Lead States, 2013). Engineering design activities are effective strategies to integrate science, mathematics, and technology and to engage students (Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006). Students' engagement with the engineering design activities can increase the quality of education in various aspects.

Students at the K-12 level should have an understanding of the core elements of the engineering design process and contexts should be designed where students can apply the design process in real-world situations (Moore et al., 2014b). There are many benefits of engineering design applications for K-12 students. As examples, exposure to engineering design process positively influences students' intellectual development (Marra, Palmer, & Litzinger, 2000) and their problem solving abilities (Li, Huang, Jiang, & Chang, 2016). Engineering design process motivates students in learning mathematics and science content (Becker & Park, 2011). In summarizing the impact and significance of these findings, it is revealed that students should be exposed to more engineering design experiences. In addressing this issue and ensuring a place for engineering design in K-12 settings, teachers have a substantial role.

The literature revealed teachers' insufficient understanding of the engineering design process (Hirsch et al., 2014). Elementary teachers do not have subject matter knowledge in engineering and they don't have experience on teaching engineering which makes them anxious in bringing engineering to their classrooms (Yu, Luo, Sun, & Strobel, 2012). Teachers need improved understanding and applications of the engineering design process, since insufficient engineering knowledge can prevent teachers from providing adequate instruction and contributing to students' success in STEM related careers (Goodale, 2013). Without a clear knowledge on teachers' understanding of the engineering design process, raising students to be competent at engineering design challenges is purposeless. Accordingly, investigating teachers' understanding can bring potential to classroom on the teachers' and ultimately the students' part. Integration of engineering into the curriculum and implementing engineering activities in the classroom requires a complete understanding of how to prepare teachers (Nadelson, Pfiester, Callahan, & Pyke, 2015). Teachers need understanding and experience when they teach a discipline that falls out of their qualifications. In this respect, it is critical that teachers improve their understanding of engineering and the engineering design process.

Teachers can be considered as the change agents in schools where their role is imperative in transforming the classrooms. However, teachers lack professional preparation and experience to teach engineering (Kimmel et al., 2006). Such preparation can be provided in a teacher professional development setting. Exposing teachers to a PD program is critical because such a setting that introduces teachers to the nature of engineering and the engineering design process can alter how teachers approach K-12 engineering education. Similar instructional interventions are commonly used in learning progressions development studies (Jin & Anderson, 2012; Nordine, Krajcik, & Fortus, 2011). A teacher PD program as a context can be helpful in capturing the differences in teachers' attitudes and their understanding of the engineering design process from lower levels to higher levels. Since implementing teaching interventions or providing instructional context are used as validation methods for learning progressions (Duncan & Hmelo-Silver, 2009), such contexts can help to test and therefore better refine learning progressions.

2.5. Teacher Professional Development Programs on K-12 Engineering Education

Professional development (PD) programs for teachers are effective for improving teachers' positive attitudes and teachers' understanding of nature of engineering and/or the engineering design process. For teachers to inspire and encourage their students towards STEM careers, they should have an awareness on engineers and what they do. This can be achieved with delivery of teacher PD programs (Avery & Reeve, 2013). PD programs have shown to be effective in increasing teachers' positive attitudes towards various new pedagogies in education such as; inclusion (Male, 2011), technology integration (Overbaugh, Lu, & Diacopoulos, 2015), and inquiry-based science education (Kapanadze, Bolte, Schneider, & Slovinsky, 2015). Other benefits of participating to PD programs on engineering can be listed as; increase in student motivation to learn more engineering and increase in student learning (Avery, 2010). Teachers expressed more control over their science teaching, felt more confidence and enjoyment in teaching following their participation to a PD program (Van Aalderen-Smeets & Van Der Molen, 2015). When teachers have experience on basic engineering principles and methods, they are comfortable in sharing their experience and knowledge with their students. They can better explain the connections of math, science and engineering (Jeffers et al., 2004) and they increase self-confidence on teaching engineering concepts and engineering design process (Goodale, 2013).

In order to motivate students and raise their confidence towards careers in science and engineering, the key is to have teachers with appreciation and understanding of engineering themselves (Jeffers et al., 2004). Teacher PD programs can influence teachers' understanding and knowledge on engineering concepts, process, and applications (Nugent et al., 2010). Through engagement in PD programs, teachers can notice the importance of integrating the engineering design process into mathematics and science (Norman, Kern, & Moore, 2010). In order to effectively integrate engineering to K-12 level education, qualified teacher PD programs are needed (Dyehouse, Yoon, Lucietto, & Diefes-Dux, 2014). According to Yoon et al. (2013), teacher PD programs are effective in increasing student classroom performance through teacher practice by contributing to their knowledge and changing their attitudes positively. Teachers' knowledge about their content area and the pedagogies are in connection with how students develop their deep understanding of engineering and with students' interest in the field of engineering (Vessel, 2011). It is critical whether teachers improve themselves in terms of their understanding of engineering and the engineering design process.

When compared to science and mathematics, there have been fewer examples of teacher PD programs on engineering and more research is needed to understand how teacher PD programs for K-12 engineering education can be more effective (Yoon et al., 2013). Teachers tend to have a fear engineering and they see it as a discipline that is only for the brightest children. For this to be overcome, a PD program can be a great opportunity for them to be exposed to engineering instruction (Cunningham, 2009; Page et al., 2013).

With PD programs, teachers are better able to promote engineering to their students (Page et al., 2013). In order to improve the learning outcomes for students, the details of such programs should be more closely investigated (Dyehouse et al., 2014). For engineering to have a place in K-12 curriculum, the question of what teacher PD programs should include for the effective integration of engineering teaching and assessment should be answered (Dyehouse et al., 2014). More research is needed to understand the effective practice of teacher PD programs for K-12 engineering education (Yoon et al., 2013). Teachers can access the knowledge, skills, and dispositions addressed in the new standards with high-quality professional development opportunities (Capobianco & Rupp, 2014). Since PD programs have an eminent role in enhancing teachers' competencies and understanding of K-12 engineering education, research efforts to better improve their design is of significance.

To design an effective teacher PD program on K-12 engineering education that can contribute to teachers' improvement as well as creating a context for validation of the learning progressions, revealing influential points in the literature was helpful. Recent previous teacher PD programs on K-12 engineering education; delivered between 2000 and 2016 were summarized in five parts: a) participant teachers in the PD programs, b) purposes and focuses of the PD programs, c) delivery format of the PD programs, d) connection to science and engineering knowledge, and e) collaboration with engineering experts. Guided mainly by these five parts, an analytical table was created on the details of the PD programs on teacher K-12 engineering education (for an overview see Table 2). The articles addressed in this table all included a teacher PD program on K-12 engineering education. Detailed information on the five summarizing parts were presented.

Table 2. *Analytical Table of Studies*

		Focus of the PD program					Science and engineering themes		
Authors	Year	Focus 1	Focus 2	Focus 3	Elementr. school	High school	Science content	Strand(s) of engineering	Follow-up; Classroom implement
Nadelson	2015	X		X	X		No specific focus stated	No specific focus stated	X
Martin	2015	X	X			X	Newtonian mechanics, basic aerodynamics,	Mechanical	
Diefes-Dux	2015	X	X	X	X		Solids and Liquids, Pollination, simple machines,	Chemical, agricultural, industrial	X
Guzey	2014	X		X	X		Changes in energy forms, waves and inquiry,	No specific focus stated	X
Dare	2014	X		X		X	Force and motion, energy, waves, heat transfer	No specific focus stated	X
Duncan	2011	X			X		No specific focus stated	Mechanical, environmental	
Hynes	2007		X	X			Gears and programming, robotics design	Bioengineering	X
Cunningham	2007	X	X	X		X	Mass, gravity, and forces	Industrial	X
Winn	2009	X		X			Collecting and interpreting data	No specific focus stated	X
Hardré	2010	X	X	X	X		No specific focus stated	Industrial, computer, environmental	X
Cejka	2006		X	X			Programming robotics, friction, gearing, and torque	No specific focus stated	X
Baker	2007	X	X	X			No specific focus stated	Industrial, bioengineering	X
Moskal	2007	X		X			Energy, sound, heat, motion, electricity	Chemical, civil, mechanical	X
Poole	2001	X	X	X	X		Velocity, microbursts, laminar, and turbulent flow	No specific focus stated	X
Iskander	2010	X					Programming robotics	Mechatronics	
Nugent	2010	X	X	X	X		No specific focus stated	Environmental, civil	X
Klein	2009	X	X	X	X		Optics, nanotechnology, medical imaging	Biomedical	X
Yoon	2013	X	X	X	X		Wind & weather, solids & liquids; simple machines,	Mechanical, chemical, industrial, packaging	X

a. Participant teachers in the PD programs. It was revealed that a majority of the PD programs included elementary teachers (e.g. Hardre, Nanny, Refai, Ling, & Slater, 2010; Nadelson et al., 2015). This was followed by the inclusion of both elementary and high school teachers (e.g. Baker, Yaşar-Purzer, Kurpius, Krause, & Roberts, 2007; Moskal et al., 2007) and only high school teachers (e.g. Martin, Baker Peacock, Ko, & Rudolph, 2015). Before high school, many students tend to lose interest in classes that are pre-requisites for advanced science, engineering, and mathematics courses (Moskal et al., 2007). It was considered an urgent need to train elementary teachers to teach engineering and to evoke their students' interest in engineering careers (Sun & Strobel, 2013). This fact was evident in the choice of elementary teachers in majority of the studies.

b. Purposes and focuses of the PD programs. For their primary purposes of delivering a PD program, commonalities were detected. In order to summarize, four purposes in preparing and implementing a PD program on K-12 engineering education were identified.

The primary purposes of the PD programs were: a) to increase teachers' understanding and knowledge of K-12 engineering education and/or engineering design process, b) to increase teachers' potential to teach engineering, c) to investigate teachers' attitudes towards K-12 engineering education, and d) to have teacher leaders in K-12 engineering education.

The first purpose; to increase teachers' understanding and/or knowledge of K-12 engineering education, involved increasing teachers' knowledge and examining what knowledge they used as they implemented engineering activities (e.g. Duncan et al., 2011). The second purpose, increasing teachers' potential to teach engineering focused on enabling teachers to enact engineering design challenges in their classroom (e.g. Dare, Ellis, & Roehrig, 2014), resulted in the integration of engineering in the K-12 curriculum. This second purpose was evident in studies that included teachers' classroom implementations following the face-to-face workshops. This goal was concerned with teachers not only learning engineering but also implementing it successfully in their classes (Hynes & Santos, 2007). A third goal was to work on and to improve teachers' attitudes towards K-12 engineering education (Hardre et al., 2010; Martin et al., 2015). The final prominent purpose was having teacher leaders in K-12 education (e.g. Cunningham et al., 2007). This purpose highlighted teachers' being able to transfer what they learnt to teachers and/or to the principles working in their schools (Cunningham et al., 2007).

In accordance with the purposes of the studies, the focuses or common variables of interest in the PD programs were: a) focus1; teachers' understanding/knowledge of engineering design and/or K-12 engineering education, b) focus2; teachers' attitudes including their perceptions, interest, recognition, and comfort towards K-12 engineering education, and c) focus3; teachers' ability to teach engineering in classroom. The review by Mendoza Diaz and Cox (2012) also reported the main focuses of teacher PD programs as teacher knowledge and teacher attitudes. Teachers participating in a PD program valued the improvement in their comprehension of the engineering design process, engineering and technology (Nugent et al., 2010; Yoon et al., 2013). PD programs were effective also in increasing teachers' positive attitudes towards teaching (Van Aalderen-Smeets & Van Der Molen, 2015). It is important to have a clear picture of teachers' attitudes, as negative teacher attitudes might serve as barriers in the successful integration of engineering practices (Yoon et al., 2013). Teacher attitudes might include teacher confidence (Hynes & Santos, 2007; Klein, 2009), teacher perceptions (Baker et al., 2007; Iskander et al., 2010; Poole, DeGrazia, & Sullivan, 2001), teacher satisfaction (Yoon et al., 2013), and teacher comfort (Cunningham et al., 2007; Diefes-Dux, 2015). Overall, PD programs seemed to contribute to teacher knowledge on engineering design and positive attitudes towards engineering.

c. Delivery format of the PD programs. The delivery of the PD programs was examined, describing the duration and the scope. The total duration of the PD programs mostly ranged from between three days and five years and was comprised of two parts: a) workshops designed as face-to-face, and b) follow-ups. Examples of face-to-face workshops were one-week-long (e.g. Cejka, Rogers, & Portsmore, 2006; Duncan et al., 2011) and two-weeks-long (e.g. Chin, Zeid, Duggan, & Kamarthi, 2011; Iskander et al., 2010; Nugent et al., 2010). A big portion of the face-to-face workshops were delivered during the summer. The reason for this was the increased amount of time the participant teachers had available to them compared to the academic year. The face-to-face workshops mainly combined presentations, discussions, and hands-on engineering activities. Most of the PD programs included follow-ups such as reunions with teachers following the face-to-face workshop. The follow-ups were in the form of teachers' classroom implementations and provided them with classroom support. Most studies had their participant teachers implement a lesson or an activity in classrooms with students and then provided improvement opportunities. The main purpose in including teacher classroom implementation was to extend professional development beyond the face-to-face workshop and to situate PD in the classrooms (Nadelson et al., 2015). Classroom implementations enabled the teachers to practice integrating engineering with science and math concepts (Cunningham et al., 2007).

Teachers implemented engineering design lessons with their students as they were observed by the PD program providers (Nadelson et al., 2015). Field notes taken by the PD program designers during classroom observations were combined with teacher interviews to better understand how teachers were using what they learnt in face-to-face workshops (Avery & Reeve, 2013). This resulted in teachers reflecting on their implementation practices. Teachers reflected on their experience of implementation as they evaluated how they can synthesize their new knowledge of engineering with the science, math, or technology concepts they need to teach in class (Dare et al., 2014; Nadelson et al., 2015). Teachers' reflections on their experiences following their classroom implementations and on possible improvements for the future were also a part of classroom observations. The reflections included successful strategies they used with their students and what additional support, training programs and/or resources they needed (Hynes & Santos, 2007). A variation of this kind of support to teachers was introduced by Hynes (2012) that included options for teachers: (1) a two-week summer workshop that included class implementation, and (2) a five-day school year workshop with no class implementation. The workshops designed face-to-face and the follow-ups seemed to be effective in terms of facilitating the integration of engineering in K-12 education by the teachers.

d. Connection to science and engineering knowledge. Inclusion of appropriate science content is critical for an engineering design activity, in that it helps improve the design of engineering products (Kolodner et al., 2003). The PD programs offered a variety in terms of their choice of science content. The majority of the teacher PD programs on K-12 engineering education had an overarching science content focus. Some of the most common science content covered with the engineering design challenges were energy conversion, energy resources, and wind energy (e.g. Guzey et al., 2014; Moskal et al., 2007), force and motion, matter, and chemical reactions (e.g. Cejka et al., 2006; Dare et al., 2014).

Most of the PD programs selected a certain strand(s) of engineering for their PD programs. With a certain strand of engineering as an overarching theme, this theme was reflected in all aspects of the PD program. Because engineering is not a single subject but on the contrary a set of separate disciplines (Martin et al., 2015), having more than one strand as a theme was considered prominent. This thematic structure seemed to contribute to the PD having a focus which offered the teachers a more comprehensive and deeper-level understanding of engineering.

Introducing knowledge on K-12 engineering education, the engineering design process (e.g. Duncan et al., 2011), the nature and practice of engineering (e.g. Guzey et al., 2014; Yoon et al., 2013) the work of engineers and how their work interacts with the society (Cunningham et al., 2007), the similarities and differences between engineering and science/scientific inquiry, (e.g. Guzey et al., 2014; Richards, Hallock, & Schnittka, 2007), engineering and technology in everyday items (Duncan et al., 2011) addressed the engineering subject matter knowledge covered in the PD programs. This was in line with the comprehensive conclusions by Hynes (2012) on teacher subject matter knowledge in K-12 engineering education which included engineering design, basic concepts of engineering and technologies, engineering tools, and the engineering profession. Focusing on subject matter knowledge on engineering in the PD programs was noteworthy since most teachers had little or no background knowledge in engineering (Lehman et al., 2014).

e. Collaboration with engineering experts. Collaboration with engineering experts was noticed to be helpful in further extending the experience of the teachers (Iskander et al., 2010). The engineering experts that took part in and facilitated the PD programs included engineering faculty members (Duncan et al., 2011; Hardre et al., 2010; Nugent et al., 2010), engineering students (Cejka et al., 2006) and engineers working in the field (Cunningham et al., 2007; Hynes & Santos, 2007; Winn, Lewis, & Curtis, 2009).

Teachers had sufficient time to work with engineering experts while developing their engineering design units (Winn et al., 2009). In terms of the role of engineering experts, they gave presentations on their methods and tools, how they approach and solve real-world problems (e.g. Avery & Reeve, 2013; Nugent et al., 2010; Winn et al., 2009), they assisted teachers in implementing engineering design activities and answered teachers' questions (e.g. Moskal et al., 2007), and they took part in panels with teachers (e.g. Yoon et al., 2013). Teachers engaged in discussions where they learnt what engineers do and how they do it (Winn et al., 2009). Teachers seemed to have strong connections with engineering experts in working on problem solving with real-world applications (Moskal et al., 2007). Overall, the literature suggested evidence on the benefits of collaborating with engineering experts in the design and delivery of PD programs.

In addition to the five-summarization points clarified, the teacher PD programs towards K-12 engineering education most commonly included five effective instructional techniques. These techniques were: a) engineering design activities, b) field trips, c) professional learning communities (PLCs), d) teacher design teams, and e) presentation of final design projects.

a. Engineering design activities. The context of engineering design is effective for learning science, mathematics and technology content (Richards et al., 2007). The hands-on engineering design activities in the PD programs modeled the engineering design process and provided chances for teachers to reflect on how to teach engineering design (Nadelson et al., 2015). The PD programs exemplified the engineering design activities with; designing the most efficient paper helicopter, building the tallest structure possible on an inclined plane (Nadelson et al., 2015), designing hand pollinators and plant packages, building an index card tower to meet specific height and load requirements (Diefes-Dux, 2015), designing the most durable package for the least amount of money (Duncan et al., 2011), designing and building a water filter and designing devices that help handicapped people (Cunningham et al., 2007), activities on wind power, solar cars, water filtration (Richards et al., 2007), and designing bridges and highways (Moskal et al., 2007; Nugent et al., 2010). The engineering design activities seemed to be concerned with the products used in daily life, design skills, and in particular the engineering design process steps.

Although the PD programs did not follow the same exact engineering design process steps in their design activities, the steps followed by teachers in solving design problems were similar and covered the basic three stages: "(a) introduction of problem and background, (b) planning and implementing, and (c) testing and evaluating" (Moore et al., 2014b, p.9). The engineering design problems included multiple acceptable solutions (Martin et al., 2015). Teachers' participation in these activities was important, as they can implement engineering design processes in their classrooms to motivate students in learning mathematics and science content (Becker & Park, 2011).

A major commonality of the engineering design activities was having a real-world context (e.g. Guzey et al., 2014; Martin et al., 2015; Poole et al., 2001). The real-world connection referred to having concerns such as a budget, time management, risk assessment, product reliability and safety and customer needs and demands (Richards et al., 2007). PD programs having a real-world connection played a crucial role because a real-world focus within engineering problems helps students grasp and retain the engineering concepts more easily (NRC, 2009, p. 51). A recurring commonality among the engineering design activities was the use of easily accessible materials (e.g. wooden blocks, rubber bands). The PD programs' consistent emphasis on using simple and easily accessible materials exemplified the possible simplicity of showing students the relationship between engineering and daily life. Some of the PD programs use more sophisticated tools and software as well (Reimers, Farmer, & Klein-Gardner, 2015) such as; PCS BrickLab (Nadelson et al., 2015) LEGO Mindstorms kits (Martin et al., 2015), LEGO Robotics kits (Cejka et al., 2006; Hynes & Santos, 2007; Hynes, 2012), CAD/CAM (3D Modeling) (Chin et al., 2011), and sensors (Iskander et al., 2010). Although these materials might be more difficult to access, they seemed to present an innovative perspective to the teachers, especially when combined with the use of simple materials.

b. Field trips. Inclusion of field trips in the scope of PD programs was mentioned in many of the teacher PD programs. Examples were visits to universities' engineering labs and engineering facilities, (e.g. Nugent et al., 2010, Yoon et al., 2013), engineering research facilities (Avery & Reeve, 2013), and science museums (e.g. Iskander et al., 2010). With field trips to engineering labs, teachers were exposed to a new setting (Nugent et al., 2010). In the study by Klein (2009), teachers were paired with faculty members to visit the engineering laboratory and to facilitate their introduction to engineering tools. It was noted that field trips provided teachers with chances to be engaged in informal learning environments increasing their understanding of engineering.

c. Professional learning communities (PLCs). The purpose of the PLCs was mainly to engage teachers in interactions that can result in collaborative knowledge building (Popp & Goldman, 2016). Teachers' participation in PLCs impact their teaching practices positively (Vescio, Ross, & Adams, 2008). In PLCs, teachers worked collaboratively which reinforced their learning (Guzey et al., 2014). Teachers discussed science content and engineering design (Dare et al., 2014); teachers were motivated to learn more (Guzey et al., 2014). Teachers had time to meet and plan effective instruction in PLCs (Dare et al., 2014). PLCs are effective in develop a learning atmosphere in schools as well (Hardré et al., 2010). For teacher PD programs, PLCs and collaborative learning strategies were evidenced to be influential by Asunda and Hill (2008) as well.

d. Design teams. Teachers working in design teams as they worked on engineering design challenges improved teachers' team working skills. Teachers collaborated and took part in discussions (e.g. Dare et al., 2014; Duncan et al., 2011; Iskander et al., 2010). In the PD program described by Hardre et al. (2010), teachers even continued the discussions with their peers in an online learning community. The discussions were effective in increasing teachers' understanding of the engineering design process. Teachers were satisfied with working in design teams to solve the engineering design challenges (Avery & Reeve, 2013). Working in teams in engineering PD programs helped teachers in building coherent learning experiences (Asunda & Hill, 2008).

e. Presentation of final design projects. Teachers presented their engineering design challenge projects and/or their final products, which was followed by receiving feedback (e.g. Cejka et al., 2006; Guzey et al., 2014). This feedback included information on how their design can be refined. In this process, teachers also shared challenges they had faced in the design process and how they worked together to brainstorm potential solutions (Hynes & Santos, 2007). Each design product was separately discussed and negotiated (Martin et al., 2015).

2.5.1. Core Elements of Teacher PD Programs

Following the detailed examination of exemplary teacher PD programs on K-12 engineering education, five core elements (see Figure 2) were generated to; a) serve as a guide in design and delivery of future PD programs, and b) further understand the relationship between the commonalities among the PD programs. The five core elements were; a) engineering design activities with real world context, b) engineering subject matter knowledge, c) a thematic structure, d) face-to-face workshop, and follow-ups, and e) engineering experts. The first core element on engineering design activities consisted of four sub core elements which were; field trips, professional learning communities, design teams, and lastly, the presentation of final design projects.

The core elements complement each other and they can all play an active role in design and deliver of a teacher PD program. In the figure, the five core elements stand together in one large rectangle, addressing their irreplaceable role as part of PD programs on K-12 engineering education. The four sub-core elements were connected to engineering design activities. The reason for the demonstration of the four instructional techniques under engineering design activities was that they were part of completing the engineering design activity. By exposure to these instructional techniques, teachers could work on their engineering design activity more effectively. Engineering design activities and the four instructional techniques under these activities were explained separately.

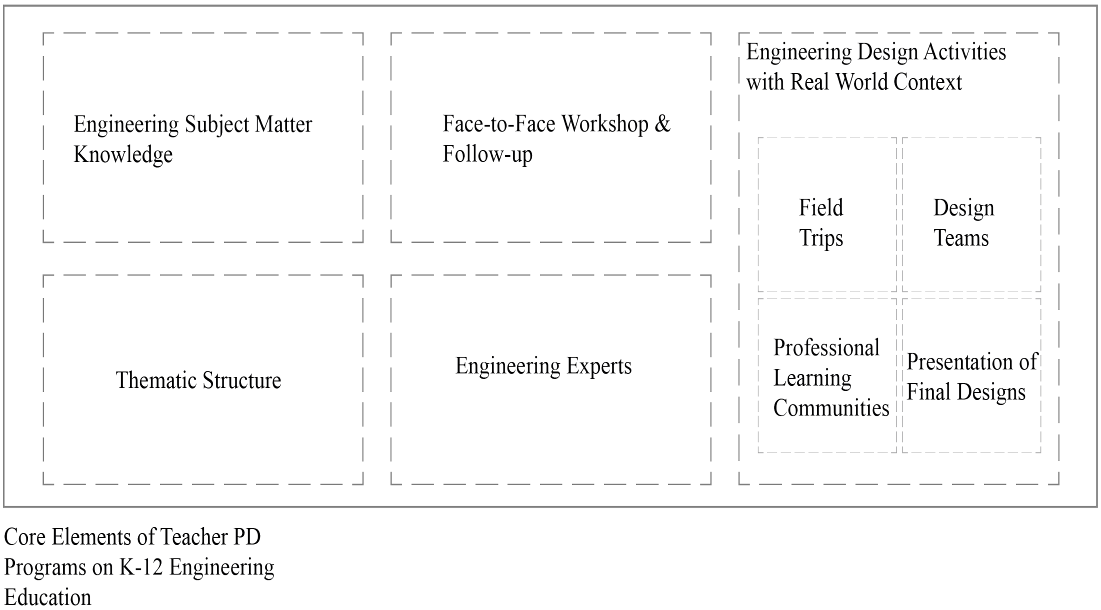


Figure 2. Core elements of teacher PD programs

The four sub-core elements should be addressed all together to ensure the optimal design of a PD program. The identification of the core elements was based on both commonalities as well as the noteworthy distinguishing features captured in the PD programs provided in Table 2. In addressing each core element separately, firstly, covering engineering subject matter knowledge aims to increase teachers' subject matter knowledge on engineering design, the nature of engineering, engineering materials, and the engineering profession. With exposure to PD programs, teachers can increase their understanding of nature of engineering and what engineers do (Duncan et al., 2011). Accordingly, focus on this core element can bring potential to classroom on both the teachers' and the students' side.

Next, the PD programs were revealed to have a thematic structure in terms of their choice for the engineering and science content strand. Rather than having isolated science and engineering content, it was suggested by the reviewed studies that engineering activities and other aspects of the PD programs should be linked under a thematic structure. In this way teachers can have a more comprehensive understanding of engineering education and better communicate the link between engineering, instruction and society to students. The next core element, having a long-term design with a combination of follow-ups and face-to-face workshops seemed to result in increased change in teachers' learning and teaching. Hoban (2002) reported the importance of long-terms efforts as follows: "The bottom line is that efforts for educational change need a long-term approach to support teachers through the non-linear process of change requiring the schools to be reconceptualised as learning environments for their teachers." (p. 39). It is critical that with this core element, teachers gain experience in teaching engineering. T continue, collaborating with engineering experts as a core element was highlighted. This kind of collaboration helped enrich the learning experience of the teachers (Hynes & Santos, 2007). Interacting with engineers provided teachers with both a safe and challenging learning environment where they took risks in questioning and creating (Duncan et al., 2011).

Lastly, the contribution of situating engineering design activities in real world contexts in terms of active engagement and enhanced learning of the participants (Asunda & Hill, 2008) was confirmed with its consistent focus in PD programs. It is important to integrate national, local or world problems to curricula and emphasize real-world contexts (Nugent et al., 2010).

The core elements were in line with the design standards for teacher PD initiatives in engineering education by Reimers et al. (2015). According to the matrix developed by Reimers et al. (2015), future teacher PD programs on engineering education should pay more attention to pedagogical content knowledge, especially activities that focus on their environments and/or local communities, and links between engineering curriculum, instruction, learning and assessment. The focus on engineering design activities based on real-world context, the use of an engineering design process where teachers learnt from failure, and the inclusion of particular science content were critical in teacher PD programs. These findings confirmed the framework by Moore et al. (2014) that depicted the elements of a quality K-12 engineering education. A focus on real-world problems and the design of products can help teachers understand how science and math content can be applied in real-life situations and show their students how engineers use science and math (Winn et al., 2009). The characteristics of effective training programs included incorporating appropriate knowledge, having necessary materials and outside speakers and/or experts, and having a long-term design (Griffin & Barnes, 1986).

Since K-12 engineering education is a very recent initiative, there are not yet much instruments to enable the assessment of teacher attitudes and teacher engineering design understanding both in the context of a PD program or in measuring teachers from different context. Learning progressions might provide an alternative perspective to assessment as they have many strengths such as development within iterative cycles of data collection and analysis, depiction of levels from novice to expert, serving as templates for assessment and instruction and their being grounded in research (Mohan, Chen, & Anderson, 2009; Plummer & Maynard, 2014; Steedle & Shavelson, 2009). Learning progressions have been studied primarily to investigate student understanding (Mohan et al., 2009; Songer, et al., 2009), but they are promising also for studying teacher learning (Schenider & Plasman, 2011).

2.6. Learning Progressions

There is a continuing interest on learning progressions in science education. Increasing number of researchers and educators design assessment tools and instructional strategies aligned with learning progressions. This focus on learning progressions research was inspired by several reports, organizations, and meetings. Some of the leading examples were "A Framework for K12 Science Education: Practices, Crosscutting Concepts, and Core ideas" (NRC, 2012)", "Next Generation Science Standards" (NGSS, Lead States, 2013), and "Developing Assessments for the Next Generation Science Standards" (NRC, 2014). The Next Generation Science Standards (NGSS, 2013) built the science concepts from in a way that reflects the progression in students' understanding of big ideas and in their skills (Bybee, 2014).

The fact that understanding develops over time was elaborated on. A particular focus on ideas getting more sophisticated in time offered the idea of learning progressions.

> "Because learning progressions extend over multiple years, they can prompt educators to consider how topics are presented at each grade level so that they build on prior understanding and can support increasingly sophisticated learning. Hence, core ideas and their related learning progressions are key organizing principles for the design of the framework" (NRC, 2012, p. 126).

With a breakthrough thinking of the alignment between curriculum, instruction and assessment, science education is arriving at a new understanding. The direction is towards building on the smaller set of basic core ideas and contents rather than a linear and compartmentalized structure of curriculum (Duschl et al., 2011). The work on learning progressions has much to offer due to the potential to bring a connection between classroom practice and research on learning (Corcoran et al., 2009). By asking questions such as; "What do we know about the typical student's entering understandings, misunderstandings and misperceptions? What do we know about the struggles students have with a particular concept? What have we learned about the steps students typically go through?" (Corcoran et al., 2009, p.16), a more effective research-based practice can be achieved (Duncan & Rivet, 2013).

Learning progressions offer new perspectives on learning and on a deeper understanding of smaller number of core concepts. As learning progressions provide an overview of students' learning across grades, they continue to be the focus in assessment, curriculum and standards discussions (Lehrer & Schauble, 2015). The major uses of learning progressions can be listed as: a) standards development, b) curriculum development, c) short-term formative assessment, d) large-scale summative assessment, and e) teacher development (Kobrin et al., 2015). Among these uses, teacher development is recently starting to receive attention. In line with this, there is a not a common agreement on how to frame the learning progressions for teachers' progress. The learning progression frameworks particular to teacher progression and development was found to be labeled differently in the literature, whereas when students' progression is the focus, the common label is learning progressions (Elmesky, 2013; Gotwals & Songer, 2013; Shea & Duncan, 2013). "Research-based core practices" (Windschitl et al., 2012, p. 879) described the progression of teachers on a set of performances such as eliciting questioning. "Learning progression framework-based measures of science teachers' knowledge" (Jin et al., 2015, p. 1271) and "teacher learning progressions" (Schneider & Plasman, 2011, p. 535) were the other denotations of learning progressions for teacher development. There found not to be an agreement when it comes to labeling learning progressions for teacher development.

A unique perspective is the developmental view; a "growth perspective" (Krajcik, 2011, p.155) embedded in learning progressions. This perspective invites educators to describe learning as a process where complexity increases. Learners gain expertise along ordered levels (Shea & Duncan, 2013) and they move from simple to complex understandings (Plummer & Krajcik, 2010; Songer et al., 2009). Sophistication in thinking, and reaching higher levels of the construct of interest can be documented theoretically an empirically with this new way of tracking progress. Learning progressions can have their associated instruments that help map the respondents along the learning progressions levels. The instruments are developed together with the learning progressions.

Learning progressions are typically developed through a series of steps that include review of literature findings, item paneling where experts share their opinions, interviews, developing draft or initial versions of learning progressions, collecting data with instruments associated with learning progression levels. Following these steps results in refining and validating the learning progressions in multiple research cycles. As data is collected with the instruments associated with the learning progressions, levels and the items of associated instruments if any should be revised in response to empirical evidence obtained (Alonzo & Steedle, 2009). In order to validate the initial versions of the learning progressions and to use their associated instruments as assessment tools in both large-scale and in PD contexts, items should be revised to their final to form (Alonzo & Steedle, 2009). The highest level of the learning progressions; the upper anchor is usually based on standard documents, literature findings, and cognitive science research (Alonzo & Steedle, 2009). The middle and the lower levels or the lower anchors of the learning progressions are constructed again through a review of literature and also through initial empirical data collection and analysis (Wilson, 2005).

Learning progressions having a hypothetical nature (Gotwals & Songer, 2013; Steedle & Shavelson, 2009; Stevens et al., 2010). They are revised following iterative data cycles (Mohan et al., 2009). Even though learning progressions are empirically validated, the fact that they were hypothetical and inferential (Stevens et al., 2010) should be kept in mind. This approach can provide a unique perspective by describing learning of core concepts in a domain as it unfolds (Duncan et al., 2009). Learning progressions received great attention due to their impact of how they guide learning (Van Rijn, Graf, & Deane, 2014). Learning progressions can be developed with different purposes that is also related to their grain size. The grain size can be large or small allowing for zooming in or zooming out. Grain size can be considered as the amount of content in a single level or the range of difference between levels (Kobrin et al., 2015). A large grain size can be too overwhelming whereas a very small grain size can make it hard to evaluate in terms of levels (Kobrin et al., 2015). In majority of learning progression development studies, participants are tracked for a longer period of time such as one academic year to be able to capture the progression (Todd & Kenyon, 2015), and large samples sizes are noticed (Duncan, Castro-Faix, & Choi, 2016; Testa et al., 2015; Todd & Kenyon, 2015).

Mostly learning progressions in the literature were developed to reveal levels of students' understanding and thinking. Some examples can be listed as: biodiversity (Songer et al., 2009); substance (Johnson & Tymms, 2011) modern genetics (Duncan et al., 2009), and explanation construction (Songer & Gotwals, 2012), quantitative reasoning within environmental science (Mayes et al., 2014); modern genetics (Duncan et al., 2009), and water in environmental systems (Gunckel et al., 2012) (see Table 3).

Table 3. *Exemplary Learning Progressions for K-12 Students*

Learning Progressions for K-12 Students on Disciplinary Core Ideas and Practices (NRC, 2012)	
Physical Sciences	Alonzo & Steedle, 2010; Black, Wilson, & Yao , 2011; Jin, Zhan, & Anderson, 2013; Johnson & Tymms, 2011; Neuman, Viering, Boone, & Fischer, 2013; Smith, Wiser, Anderson, & Krajcik, 2006; Stains, M., Escriu-Sune, Molina Alvarez de Santizo, & Sevian, 2011; Steedle & Shavelson, 2009; Stevens, Delgado, & Krajcik, 2010
Life Sciences	Duncan, Castro-Faix, & Choi, 2014; Duncan, Rogat, &Yarden, 2009; Elmesky, 2013; Gotwals & Songer, 2013; Gunckel, Covitt, Salinas, & Anderson, 2012; Jin & Anderson, 2012; Lehrer & Schauble, 2012; Mohan, Chen, & Anderson , 2009; Shea & Duncan, 2013; Songer & Gotwals, 2012; Songer, Kelcey, & Gotwals, 2009
Earth and Space Sciences	Plummer & Krajcik, 2010; Plummer, 2014; Plummer & Maynard, 2014
Practices	Berland & McNeill, 2010; Mayes, et al., 2014; Lehrer & Schauble, 2012; Songer & Gotwals, 2012; Songer, Kelcey, & Gotwals, 2009; Wang, Ho, & Cheng, 2015

There are recent efforts to document teachers' understanding as well as teacher performance with learning progressions as well. Some examples were teacher learning progressions that mapped teachers' performance eliciting students' ideas, choosing activity, and pressing for explanation (Windschitl et al., 2012) and teachers' thinking on astronomy concepts (Plummer & Slagle, 2009).

Usage of multiple data sources during learning progression development was another commonality noticed; multiple choice items and fill in the blanks used together (Songer et al., 2009), open-ended questions and interviews used together (Jin et al., 2013; Stevens et al., 2010), and open-ended questions and multiple-choice questions used together (Gotwals & Songer, 2013; Liu, Lee, Hofstetter, & Linn, 2008). Gunckel et al. (2012) noted that, "Using empirical results, we were able to better articulate lower anchor and intermediate levels of student achievement" (p.852). For the refinement of the learning progression levels, empirical evidence has a critically important role. The most frequently used data collection methods can be reported as interviews (Stevens et al., 2010), written artifacts such as open-ended explanations (Alonzo & Steedle, 2010; Gotwals & Songer, 2013; Jin et al., 2013), ordered multiple choice (OMC) items (Hadenfeldt, Neumann, Bernholt, Liu, & Parchmann, 2016), and multiple-choice items (Gotwals & Songer, 2013; Neumann et al., 2009). Some of the studies created these data collection tools by bringing together items published in standardized examinations (Lee & Liu, 2010) or with investigation of existing research on student understandings (Hadenfelt et al., 2013; Johnson & Tymms, 2011; Steedle & Shavelson, 2009).

The development of a learning progression can be summarized as first creating levels from low to high based existing literature sources. This can be followed by revealing the quality of this initial ordering of levels; validation of the learning progression. Therefore, the initial versions of the order of the levels need refinement which can be done through collection and analysis of empirical data (Testa, Galano, Leccia, & Puddu, 2015). Use of empirical evidences are basically validation methods of the learning progression's initial version. Validation methods for the initially constructed learning progression levels include developing an associated instrument with the learning progression; that is aligned with the levels of the learning progression (Alonzo & Steedle, 2009; Nguyen & Griffin, 2012), use Rasch analysis (Lee & Liu, 2010; van Rijn et al., 2014), deliver a teaching intervention or curricular activities (Jin et al., 2013; Songer et al., 2009), and use empirical data not necessarily collected with an associated instrument (Jin et al., 2013; Mohan et al., 2009). A figure depicting the possible strategies for development and validation of learning progressions can be examined in Figure 3.

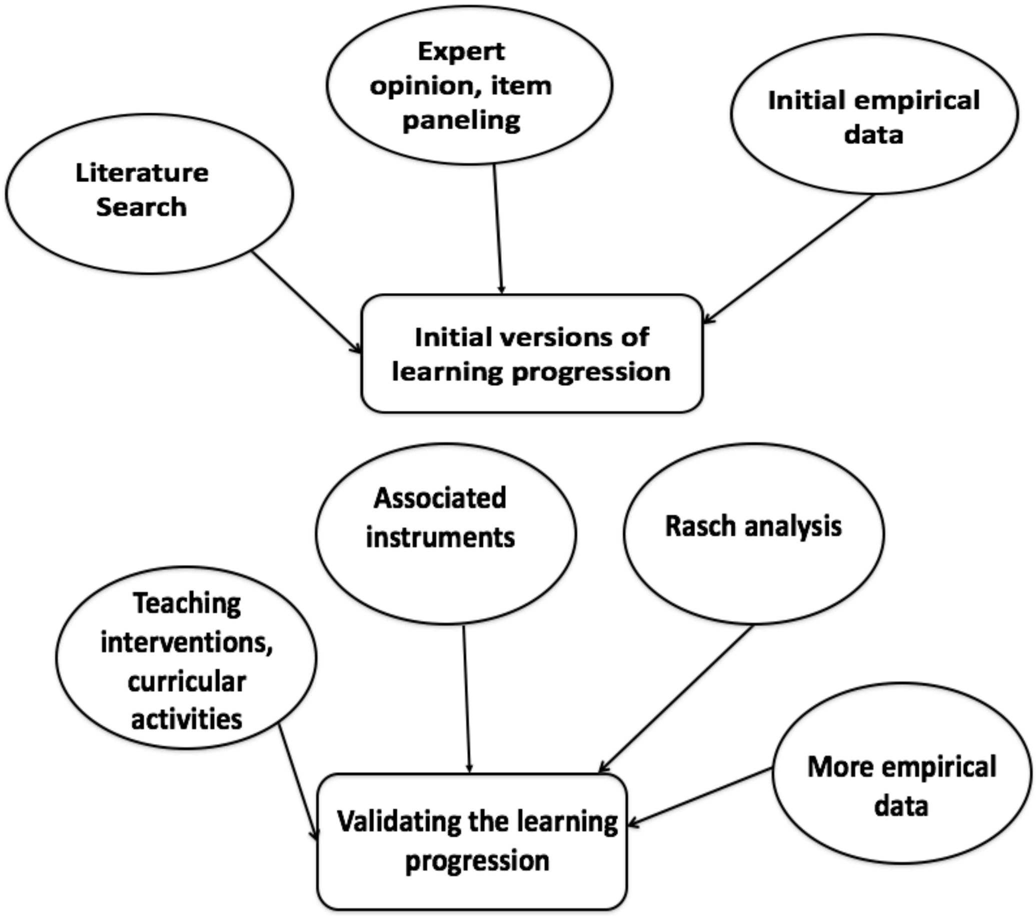


Figure 3. Commonly used development and validation processes

Collaborating with experts (Gotwals & Songer, 2013), engaging in reflective discussions among the research group (Elmesky, 2013; Mohan et al., 2009; Songer & Gotwals, 2012), and collaborating with teachers (Furtak et al., 2012; Furtak & Heredia, 2014) are some other ways of refining the levels of the learning progressions. For the case of developing a learning progression with its associated instrument, an example learning progression and one of the items in the instrument can be examined in Figure 4 (Alonzo & Steedle, 2009).

When it comes to evaluating a developed learning progression and revealing its strengths and areas for improvement, the study by Kobrin et al. (2015) can be useful. The authors built a framework that can be used to evaluate and interpret the key features of a developed learning progression. This framework can be useful for practitioners and educators to understand and evaluate the learning progression they develop; whether it serves it purpose or not.

Construct maps are smaller versions of learning progressions, as learning progressions might include several construct maps depending on the focus of study (Wilson, 2009). A single construct map or a larger learning progressions both are helpful for tracking the progress on the construct of interest. Learning progressions are effective in depicting the progress towards a big idea and construct maps can be useful when the focus in on smaller grain size (Alonzo & Steedle, 2009). A construct can belong to a conceptual model of a person's cognition, such as understanding of consepts, it can be attitude toward something, or it can be a psychological variable such as need for achievement or a personality variable such as a bipolar diagnosis (Wilson, 2005). An early version of a learning progressions can be considered a map of student ideas or a construct map (Wilson, 2005). Construct maps "defines what is to be measured and assessed" (Wilson, 2009, p. 718). Figure 5 depicted a possible relationship between a construct map and a learning progression.

The literature included examples of construct maps developed on attitudes; attitudes of students and parents towards schooling (Nguyen & Griffin, 2003), and teachers' attitudes toward inclusive education (Mahat, 2008). In these examples, the construct maps were validated thorough developing an associated instrument and conducting a Rasch analysis to investigate the empirical alignment between the instrument and the construct map levels. An example of a construct map and an item from its associated Likert-type survey can be examined in Figure 6. In addition to being a smaller and a less complex version of a learning progression, another reason for labeling a *learning progression* as a *construct map* is that the development and refinement processes follow the construct modeling methodology (Wilson, 2005).

Initial Version of the Force and Motion Learning Progression

Level	Description
5	Student understands that the net force applied to an object is proportional to its resulting *acceleration* (change in speed or direction), and that this force may not be in the direction of motion. Student understands forces as an interaction between two objects.
4	Student understands that an object is stationary either because there are no forces acting on it or because there is no *net* force acting on it. However, student may have misconceptions related to a belief that the applied force is proportional to an object's speed or motion (rather than its acceleration). Student can use phrases such as "equal and opposite reaction" to justify the existence of no net forces but may not understand this as an interaction. Common Errors: • Motion is proportional to the force acting. • A constant speed results from a constant force. • Confusion between speed/velocity and acceleration.
3	Student recognizes that forces are not *contained* within moving objects; however, student believes that motion implies a force in the direction of motion and that nonmotion implies no force. Common Errors: • Forces are associated only with movement. • Forces are viewed as causing things to move but not causing things to stop. • If there is motion, there is a force acting. • If there is no motion, then there is no force acting. • There cannot be a force without motion. • When an object is moving, there is a force in the direction of its motion.
2	Student recognizes that forces can be caused by nonliving things; however, student may believe that forces reside in within moving objects. Common Errors: • A moving object has a force within it that keeps it going. • A moving object stops when its force is used up.
1	Student understands forces as a push or pull, but believes that only living or supernatural things can cause forces.

Derek throws a stone straight up into the air. It leaves his hand, goes up through point A, gets as high as point B and then comes back down through A again.

a) Original item

When the stone is on its way up through point A, what force(s) are acting on it?	**Level**
A. Only gravity is acting on the stone.	Level 4*
B. Only the force from Derek's hand is acting on the stone.	Level 3*
C. A force inside the stone is keeping it moving upward.	Level 2*
D. Both gravity and the force from Derek's hand are acting on the stone, but the force of gravity is smaller.	Level 3*
E. There are no forces acting on the stone because nothing is touching it.	Level 1*

Figure 4. Example LP and its OMC item (Alonzo & Steedle, 2009, p. 397, 400)

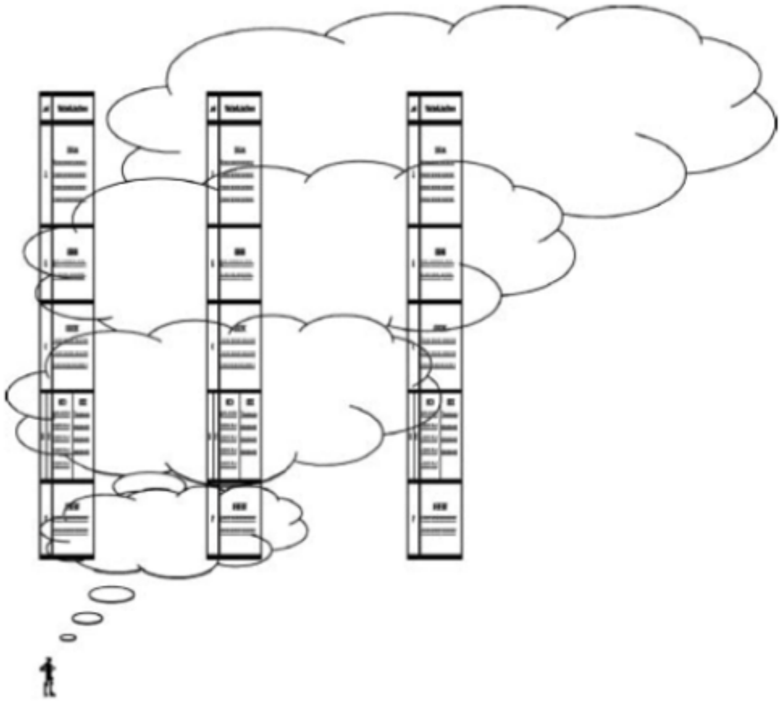
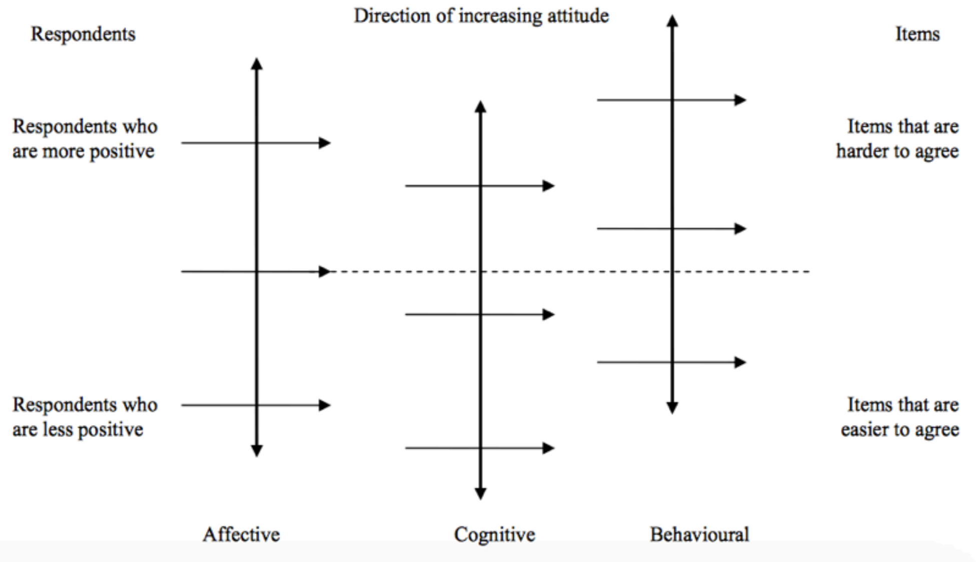


Figure 5. Possible relation between a Construct Map and a LP

The constructs should have a direction, order, a level of magnitude and replicable units (Wright & Masters, 1982). Understanding is better conceptualized as a continuum, compared to a dichotomy (Briggs, Alonzo, Schwab, & Wilson, 2006) which can be identified effectively with levels of a construct map.

The current study focused on a construct map to track teachers' attitudes where the development and refinement procedures followed construct modeling measurement framework as stated above. However, in order to maintain a consistent language throughout the study, *learning progression* was the common denotation for both focuses; teacher attitudes and teacher understanding of the engineering design process.



Example item: I believe that an inclusive school is one that permits academic progression of all students regardless of their ability. *Strongly Agree*, *Somewhat Agree*, *Agree*, *Disagree, Somewhat Disagree* and *Strongly Disagree*

Figure 6. Example Construct Map and its item (Mahat, 2008, p. 85)

Differentiating from traditional interviews, particular types of interviews were used such as clinical interviews (Johnson & Tymms, 2011; Mohan et al., 2009; Shea & Duncan, 2013) and think aloud interviews (Songer et al., 2009) to gather data for learning progressions. Such interviews were promising data collection methods which were more closely examined in the following sections.

Cognitive interviews and clinical interviews are techniques helpful for learning progressions development (Breslyn et al., 2016; Mohan et al., 2009; Wilson, 2009). These techniques are effective in increasing the quality of the learning progressions frameworks and also their associated instruments if any. Think alouds, cognitive interviews and clinical interviews were recognized to be used interchangeably in learning progression development studies in terms of labeling the data collection method. In order to elicit and further investigate thinking processes on a certain construct of interest, learning progression studies mainly refer to the interviewing strategy as think alouds and clinical interviews. Some learning progression studies refer to think aloud and cognitive interviews together in their interview protocol (Gotwals & Songer, 2013). When carefully considered, it was noticed that think-alouds were the common point in learning progression development studies with the goal of eliciting teachers' thinking. Some studies preferred to entitle the interview technique solely as think alouds only, whereas some other studies referred to the technique as clinical interview (Mohan et al., 2009) which includes a think-aloud part. Whatever terminology is used, the main goal of this type of data collection is to help reveal respondents' thinking processes in detail.

Clinical interviews are commonly used in learning progression development studies (Gotwals & Songer, 2013; Plummer & Krajcik, 2013; Schwarz et al., 2009). They are highly influential in understanding the differences in respondents in terms of the variable or construct of interest (Jin & Anderson, 2012). The clinical interviews can include think aloud procedures to investigate teachers' thinking processes (Ericsson & Simon, 1993) as they work on various tasks introduced by the interviewer. Learning progression development studies use both think-alouds and clinical interviews to explain their data collection methods.

The literature contained examples of studies collecting data with written assessments or teacher logs and clinical interviews together while developing learning progressions (Jin et al., 2013; Mohan et al., 2009). This was especially the case when the iterative process of learning progression development is at its first cycle, which basically refers to a more exploratory effort to document the possible levels of the learning progression. Usage of written assessments and teacher logs together with interviews are useful to provide a great range and variety of information on respondents' thinking (Songer et al., 2009). Teacher logs are effective in providing a real time data. They are collected repeatedly over time to create snapshot of learning (Glennie, Charlers, & Rice, 2017). In depth interviews most importantly help elicit the thinking of the respondents (Breslyn et al., 2016) so that differentiating levels of the learning progression can emerge. Learning progressions research commonly make use of interviews and think alouds in revising the hypothetical learning progressions framework (Hess, 2008). This study used teacher logs together with clinical interviews to better inform the levels of the learning progression on teachers' understanding of the engineering design process.

Cognitive interviewing is another helpful method that frequently used in psychology and clinical research to improve the quality and to test the reliability and validity of instruments. The method has its origins in psychology and in survey methodology (Willis, 2015). Cognitive interviews were used in psychology and medicine to revise the following instruments: Quality of Trauma Measure (Bobrovitz, Santana, Kline, Kortbeek, & Stelfox, 2015), Epilepsy Module (Follansbee-Junger et al., 2016) and a Grief Measure for Adolescents (Taylor, Thurman, & Nogela, 2016). Another field of research is forensics that typically make use of cognitive interviews (Bembibre & Higueras, 2011; Davis, Mcmahon, & Greenwood, 2002) with the goal of bringing about more accurate testimonies. Cognitive interviews as evaluation tools are successful in overcoming measurement challenges in educational research (Sopromadze & Moorosi, 2016). Cognitive interviews are used in educational research frequently in order to increase the validity of instruments being developed. The items on an instrument can be understood from the perspective of the respondents (Drennan, 2003) before the actual data collection takes place. Cognitive interviewing is a helpful technique to investigate the extent to which instruments validly and reliably capture respondents' experiences (Desimone & Le Floch, 2004). Cognitive interviewing helps to reveal the internal mechanisms that underlie survey responses (Willis, 2015) and to refine the items in an instrument (Bernbaum Wilmot, Schoenfeld, Wilson, Champney, & Zahner, 2011). Cognitive interview focuses on "the administration of draft survey questions while collecting additional verbal information about the survey responses, which is used to evaluate the quality of the response or to help determine whether the question is generation the information that its author intends" (Beatty & Willis, 2007, p. 287).

While cognitive interviews have been used extensively in other fields, for education researchers this technique is not used often (Desimone & Le Floch, 2004). Cognitive interviewing is quite different from traditional piloting of items in that cognitive interviews provide data on how the items are interpreted by the participants and whether they are confident is responding. In application of an instrument, results have little meaning if the respondent cannot comprehend the items as assumed (Wildy & Clarke, 2009). Some additional example instruments where the items were refined with cognitive interviews can be listed as Mathematics-Related Beliefs Questionnaire (MRBQ), teacher goal scales, and International Study of Principal Preparation (ISPP) Survey (Sopromadze & Moorosi, 2016). The results of the cognitive interview data analysis give information on whether the items on the instrument function as hypothesized.

During a cognitive interview, participants provide information about their thoughts regarding each item on the survey (Willis, 2015). Cognitive interviewing designs can be mostly in two general forms: the "think aloud" approach and the "verbal probing" approach (Collins, 2003; Willis, 2015). Think-aloud is mostly conducted by requesting the participant to tell everything they are thinking as they answer the question. Similar and very general questions can be asked for the think-aloud part. With think-alouds, participants are encouraged by the interviewer to try to report everything as they go through the items; reflection of their experience, what is unfamiliar to them, and any other thoughts (Desimone & Le Floch, 2004). For verbal probing, it demands more from the part of the interviewer since they require much more structure on the interview protocol with the various forms they can take (Willis, 2015). As traditional rehearsal and piloting of surveys by itself is not sufficient (Collins, 2003), cognitive interviews brings about an effective way of improving instruments. When it comes to cognitive interviews, the main goal is to improve the overall quality of an instrument developed. Cognitive interview offers results that cannot be obtained with piloting, which is a more common strategy.

2.7. Summary of the Literature Review

When the educational demands of the 21st century are considered, it is a clear need for teachers to be equipped with the necessary understanding and skills on K-12 engineering education. For teachers' successful integration of engineering concepts and practices to their instruction, their attitudes and comprehension engineering design process are significantly critical. In order to measure and understand teachers' attitudes towards K-12 engineering education, and their understanding of the engineering design process in a more systematic way, learning progressions can be helpful tools. For the development and validation of learning progressions, several strategies are followed including but not limited to, developing associated instruments, implementing curricular activities for longer periods such as through an academic year, and using instructional contexts.

Teacher professional development (PD) programs are helpful instructional contexts for teachers to increase their positive attitudes towards K-12 engineering education. With various instructional opportunities, teacher PD programs can also contribute to teachers' learning of the engineering design concepts and gain an understanding of the engineering design process. The current study aimed to develop empirically supported teacher learning progressions that can help to document teachers' progress on a continuum of; a) attitudes towards K-12 engineering education, and b) engineering design process understanding. The empirical tools developed and refined were a learning progression and its associated survey for teachers' attitudes and a learning progression on engineering design process. During the process of developing these empirical tools, a PD program was used as an instructional context to collect and analyze data for validation purposes. PD program also aimed to improve teachers in K-12 engineering education. Development of a survey and analysis of data with Rasch analysis were the other validation strategies. All procedures followed to develop and refine the learning progressions were explained in the following chapters.

CHAPTER 3

METHODOLOGY

3.1. Design-Based Research

In developing; a) the teacher learning progression on attitudes and its associated survey; "Science Teachers' Attitudes towards K-12 Engineering Education Survey", and b) the teacher learning progression on understanding of the engineering design process, design-based research (DBR) (Collins, Joseph, & Bielaczyc, 2004) was put into practice. According to The Design-Based Research Collective (2003), "Design-based research can help create and extend knowledge about developing, enacting, and sustaining innovative learning environments" (p. 5). Design-based research has its roots in the educational designs of Collins (1992) where a systematic method for performing design experiments was elaborated on. Design-based research contributes to many issues in the study of educational practices and in developing educational tools. Collins et al. (2004) reported some of the examples issues as "the need to address theoretical questions about the nature of learning in context, the need for approaches to the study of learning phenomena in the real world" (p. 16). According to Anderson and Shattuck (2012): "design practice usually evolves through the creation and testing of prototypes, iterative refinement, and continuous evolution of the design, as it is tested in authentic practice" (p. 17). The major characteristics of design-based research can be summarized as (Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006a):

> "Interventionist: The research aims at designing an intervention in the real world, Iterative: The research incorporates a cyclic approach of design, evaluation, and revision, Process Oriented:

> A black box model of input-output measurement is avoided, the focus is on understanding and improving interventions, Utility Oriented: The merit of a design is measured, in part, by its practicality for users in real contexts, and Theory Oriented: The design is based upon theoretical propositions, and field testing of the design contributes to theory building" (p. 5).

Design-based research requires the collaborative work of researchers, practitioners and similar other relevant parties (The Design-Based Research Collective, 2003). Although there is no single design based method to follow as a one-to-one, still the critical significance of context on learning design (Barab & Squire, 2004), inclusion of multiple data cycles, and collaborations between researchers and practitioners (Anderson & Shattuck, 2012) are some of the distinguishing elements of design-based research. According to Sandoval and Bell (2004), in following design-based research, many disciplines and fields are investigated such as "developmental psychology, cognitive science, learning sciences, anthropology, and sociology" (p. 200).

With use of design-based research in the current study, a better link between theory and practice could be presented. Designed contexts change with revisions where successive iterations play an important role (Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003). Learning progressions needs to be refined following multiple iterations; data collection and analysis cycles. Since development of learning progressions aim to make refinements following cycles of data collection and analysis in a designed instructional context, design-based research provided critical insights. Building learning progressions is an iterative process where the theoretical model is created with investigation of related literature and then verified with empirical data which is typical of design-based research (Mohan et al., 2009). Design-based research helped to achieve a systematic way for developing and revising the learning progressions of the current study. Design-based research approach contains progressive refinements in design which refers to putting initial versions of a product into practice and investigating how it performs. This requires constant revisions based on analysis of data. In line with this, learning progressions are refined with data collection and data analysis, and their initial versions are validated (Collins et al., 2004). The progressive refinement embedded in design-based research approach is compatible with the development process of learning progressions. Following the data collection and data analysis, the levels of learning progressions and their associated instruments can be refined (Alonzo & Steedle, 2009). Design-based research guided the current study in development and refinement of; a) the teacher learning progression on attitudes and its associated survey; "Science Teachers' Attitudes towards K-12 Engineering Education Survey", and b) the teacher learning progression on engineering design process understanding.

3.2. Research Design

The research design of the current study highlighted the three critical aspects of design-based research in particular. These aspects were preliminary research, development and prototyping, and assessment (Van den Akker et al., 2006b). The rationale for the emphasis on these aspects was that the development of learning progressions also relies on previous informative literature findings, on developing a prototype; initial versions of the learning progressions, and finally on assessing the quality of initial versions and making refinements. Learning progression research typically results in educational products to be used in educational settings for the purposes of tracking progress, assessing learning, developing curriculum, and administering instructional interventions (Furtak, Thompson, Braaten, & Windschitl, 2012; Kobrin et al., 2015; Wilson, 2009; Wiser, Smith, & Doubler, 2012). The perspective that design-based research presents was helpful in finalizing the two learning progressions, survey on teacher attitudes, and the teacher PD program where conclusions based on research findings were gained (Hernández, Couso, & Pintó, 2015). In development of learning progressions, use of design-based approach was apparent (Jin et al., 2015; Stevens et al., 2010) in making refinements following data collection and analysis cycles.

The learning progression development process begins with the development of a hypothetical ordering of levels (Breslyn et al., 2016). Later the learning progression is refined with collection and analysis of empirical data (Songer et al., 2009). Development and refinement of learning progressions requires several data collection and data analysis cycles, which result in refined versions of the learning progressions. Such a process is typical of design-based research where educational products are developed and revised through iterative data cycles (Anderson & Shattuck, 2012). The learning progressions were based on existing literature; informative literature from relevant sources (Windschitl et al., 2012), and cycles of empirical data collection and analysis (Furtak, 2009; Neuman et al., 2013). The methodology framework followed can be observed in Figure 7. The current study completed one cycle of the methodology framework shown in this figure.

Learning progressions are derived in part from literature, and in part from professional judgments about what constitutes higher and lower levels, but are also informed by empirical findings (Alonzo & Steedle, 2009; Wilson, 2005). Blending all this in a systematic way where findings build on each other called for a design-based approach.

Following design-based approach for the current study included quantitative and qualitative research methods. Data sources of the study were explained in the following sections separately. The methodology framework had three distinct phases. Figure 7 depicted the three phases in a cyclical format to address the fact that, at the end of Phase 3, another development and refinement cycle can begin which exceeds the scope of the current study. With the results of the current study, the tools presented can be improved with the completion of the methodology framework in Figure 7 for the second time in future studies.

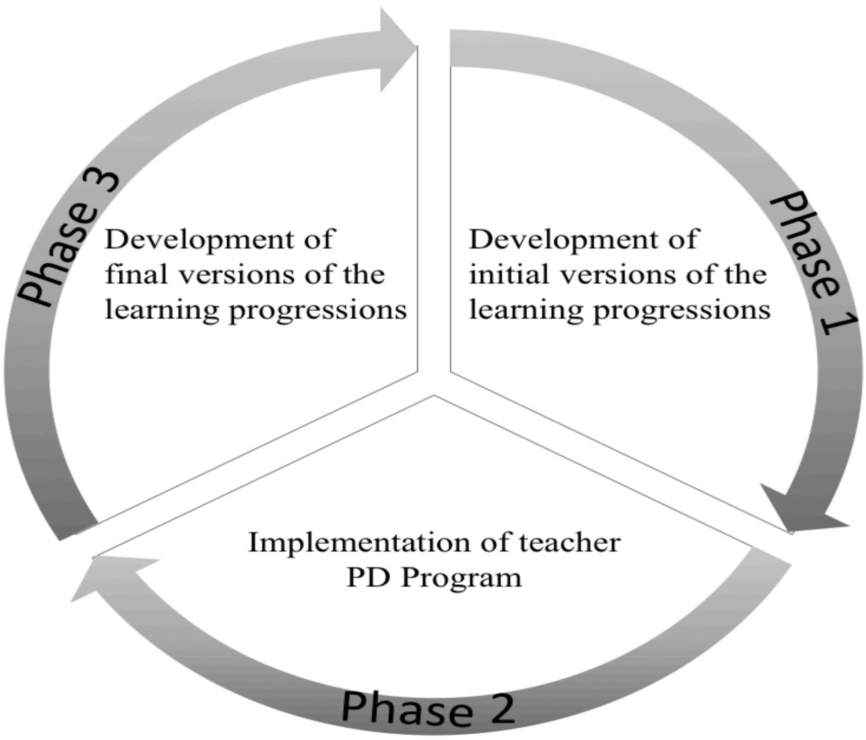


Figure 7. Methodology framework of the study

In Phase 1; development of initial versions of the learning progressions, the initial versions of the learning progressions were developed based on analysis of data accessed with searching informative literature, and analysis of empirical data collected. Levels of the learning progressions from the lowest to the highest were created. The initial versions of the learning progressions developed at Phase 1 were subject to change with the completion of the whole methodology framework cycle. Thus, the products of Phase 1 needed more empirical support which was possible through delivery of a teacher PD program. The learning progressions developed at Phase 1 guided the development of an instructional context; implementation of a teacher PD program, its curricular materials, and assessments (Jin et al., 2013) that took place in Phase 2; Implementation of teacher PD program. Phase 2 resulted in empirically-based information on how well teachers' responses fit to the learning progression levels (Songer & Gotwals, 2012). To summarize, in Phase 2, the empirical support needed to validate the learning progressions was provided with the implementation of a teacher PD program. Data was collected before, during, and after the teacher PD program. The details of the implementation of the teacher PD program and data collection procedures were presented in the following sections.

Finally, in Phase 3; development of final versions of the learning progressions with refinements were completed through the analysis of the data obtained in Phase 2 through the teacher PD program. For the current study, in order to validate or to refine the learning progressions, three strategies were utilized in total. First, in order to validate the learning progression on teacher attitudes two strategies were followed; developing an associated instrument with the learning progression (Alonzo & Steedle, 2009; Nguyen & Griffin, 2012) which was, “Science Teachers’ Attitudes towards K-12 Engineering Education Survey” and following construct modeling measurement framework (Wilson, 2005) to understand the empirical alignment of the levels and the items of the survey (Lee & Liu, 2010; van Rijn et al., 2014). Second, to validate the learning progression on teachers’ understanding of the engineering design process again two strategies were followed; providing an instructional context; implementation of a teacher PD program (Jin et al., 2013; Songer et al., 2009), and collecting empirical evidence from the participants of the teacher PD program (Jin et al., 2013; Mohan et al., 2009). These validation strategies helped to refine and increase the quality of the learning progressions in Phase 3. For the survey developed, responses to the items corresponded to the levels of the learning progression. For the learning progression on teachers’ understanding of the engineering design process, data collection and data analysis procedures were more exploratory in nature (Breslyn et al., 2016; Mohan et al., 2009) in that no associated instrument whose response categories corresponded to the levels of the learning progression was developed. The current study focused on identifying the possible levels. With future studies that complete another research cycle (see Figure 7), such an instrument can be developed which will help increase the validity of the created levels.

Both commonalities and differences existed between the steps followed to complete the methodology framework cycle in Figure 7. These commonalities and differences existed for; a) the teacher learning progression on teacher attitudes and its associated survey; “Science Teachers’ Attitudes towards K-12 Engineering Education Survey”, and b) the teacher learning progression teachers’ engineering design process understanding. Moving from this point, the methodology framework of the study was presented in Figure 8 in more detail. For the steps in developing learning progression on attitudes; the figure included “attitudes”. Likewise, fir the steps in developing learning progression on engineering design understanding; the figure included “understanding”. The figure presented the three phases of the methodology framework of the study as the main headings. Under these three phases, the similarities and the differentiating points were illustrated.

As can be observed in Figure 8, to develop both learning progressions; the learning progression for teacher attitudes and the learning progressions for understanding of the engineering design process, the commonly followed steps were literatures search; written assessments, item paneling, and refinements with analysis of data collected at Phase 2. The differentiating research steps can be listed as; cognitive interviews, survey on teacher attitudes, clinical interviews, and finally teacher logs.

The first step; literature search was the examination of informative literature. This step included a through literature search on existing sources to help identify the possible levels of the learning progressions. In this identification, critical literature findings, standard documents, were used to define what can be expected from the lower and higher levels (Alonzo & Steedle, 2009). Some of the often used literature sources helpful in identification of learning progression levels can be listed as internal logic of the domain (Plummer, 2014), indications from learning theories (Duncan et al., 2009; Elmesky, 2013; Gunckel et al., 2012), students’ understanding (Elmesky, 2013; Neumann et al., 2013), and national standards (Alonzo & Steedle, 2010; Duncan et al., 2009; Gotwals & Songer, 2013; Stevens et al., 2010).

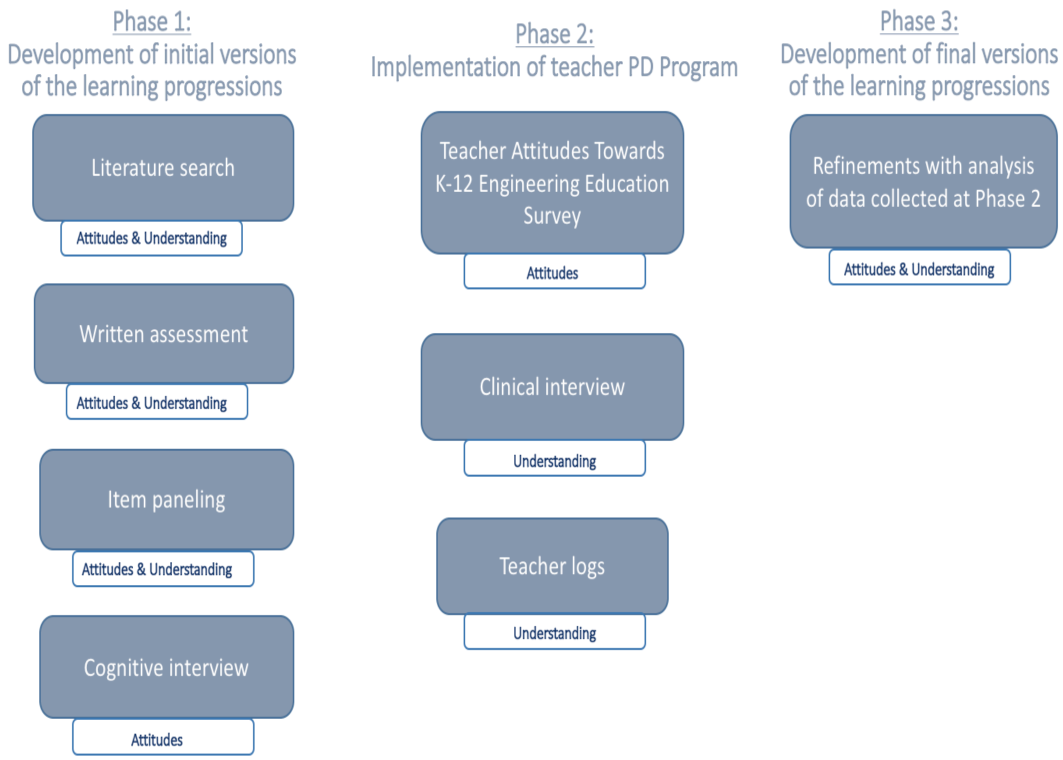


Figure 8. Methodology framework in detail

The current study made use of published articles, books, and standard documents on K-12 engineering education that contained critical information to create the initial versions of the levels. The literature search on existing informative studies also helped creation of items for developed survey on teacher attitudes; "Science Teachers' Attitudes towards K-12 Engineering Education Survey". The studies that helped to identify the levels of the learning progressions and the survey were accessed and summarized through three phases. These were: 1) Search*;* to retrieve the studies, 2) Selection*;* to apply inclusion criteria, and 3) Synthesis; to reach an overall summary of the included articles. These phases were adapted from the systematic literature methodology of Borrego, Foster, and Froyd (2015).

The second step followed to develop learning progressions was conducting written assessments (See Figure 8). Following the analysis of written assessment data, revisions were made to the learning progression levels considering the results and informative literature search. These findings were also helpful for working on items for the survey on teacher attitudes. With the analysis of written assessment data and revisions, item paneling was conducted; presenting the initial versions of the learning progressions to an expert audience. Opinion and feedback from experts was collected during the item paneling (Wilson, 2005). Item paneling included the presentation of the learning progressions and ther associated instruments or surveys if any to an audience of experts. With the panelists' ideas and suggestions for improvement, sometimes major but mostly minor revisions on the learning progressions can be made. This process is quiet similar to taking expert opinion to improve any tool being developed. However, item paneling focuses on a panel format where a presentation is made and followed by a panel discussion (Wilson, 2005). The participants of the item paneling should include potential respondents, professionals, teachers/academics and researchers in the relevant areas, and people knowledgeable about measurement in general and/or measurement in the specific area of interest (Wilson, 2005). Inclusion of such relevant people can contribute to the better improvement of the learning progression and the survey on attitudes. With the item paneling, comments, and constructive criticisms of the panelists helped to increase the quality of the products of the current study. For the learning progression and its associated instrument on teacher attitudes, the next step was to collect data through cognitive interviews from middle school science teachers. Conducting cognitive interviews increase the quality of educational measurement tools as contribute to the increased reliability and validity of surveys (Desimone & Le Floch, 2004). The main goal was to revise the Likert type survey being developed. However, the results also resulted in minor revisions to the learning progression levels on teacher attitudes.

Next, moving to Phase 2 in Figure 8, data was collected to inform and revise the learning progressions during a teacher PD program implemented. Thus, Phase 2 served as the instructional context where the learning progressions can be better revised with more empirical data. For the learning progressions on teacher attitudes, the survey on teacher attitudes was implemented both before and after the teaching

PD program. For the learning progression on understanding of engineering design process data was collected through clinical interviews and teacher logs. The teacher logs were implemented both on the first and second days of the teacher PD program. The clinical interviews were conducted following the completion of the PD program. In Phase 3, the data collected at Phase 2 was analyzed. With this analysis and necessary revisions to the learning progressions, the methodology framework cycle in Figure 7 was completed.

The three research phases together with methodology framework in detail served as a clear example for learning progression development. Revisions to learning progressions took place with analysis of empirical evidence following their research steps in Figure 8. These revisions resulted in revised version of the learning progressions. The current study presented three versions of each learning progression. The order of these versions following certain steps can be examined in Table 4. This table depicted the research steps in Figure 8 with a different organization; putting a particular focus on the versions of the learning progressions.

A detailed research alignment table that outlined the summary of the current study was illustrated in Table 5. This table outlined the research questions, goals, methods, data sources, and data analysis procedures of the study. The table presented the current study mainly based on the two guiding research questions. With such an alingment table, designing and carrying out the current study could be more coherent and organized.

Table 4. *Steps of the Methodology Framework*

	Steps	Actions
PHASE 1	Literature search	Go through the existing informative literature
	Written assessments	Collect data with open-ended written assessment questions
	Version 1 of both learning progressions and the survey on teacher attitudes	
	Item paneling	Take feedback and recommendations from experts to inform both learning progressions
	Version 2 of learning progression on teacher understanding	
	Cognitive interviews	Conduct cognitive interviews mainly to revise the survey and also the learning progression on attitudes
	Version 2 of learning progression on teacher attitudes and the survey on teacher attitudes	
PHASE 2	Implementation of Teacher PD program: Likert type scale, teacher logs and clinical interviews	Collect data with a Likert type survey to inform the learning progression on attitudes Collect data with teacher logs and clinical interviews to inform the learning progression on understanding
PHASE 3	Analyze data obtained from PD program	The data of Likert type survey, teacher logs, and clinical interviews are analyzed
	Version 3 of both learning progressions	

Table 5. *Research Alignment Table*

Purpose	Research questions	Method	Data sources	Data analysis and trustworthiness
To build a teacher learning progression to represent the progress of teachers' attitudes towards K-12 engineering education To develop a survey to validate the learning progression	How can science teachers' attitudes towards K-12 engineering education be depicted with a learning progression? How can a survey on science teachers' attitudes towards K-12 engineering education be developed to validate the learning progression?	Design-based research (DBR) approach	Informative literature (books, and standard documents for upper anchor) Written assessments Item paneling Cognitive interviews Science Teachers' Attitudes towards K-12 Engineering Education Survey	Construct modeling measurement framework (Wilson, 2005) and use of statistical package; R Studio Qualitative data analysis (Miles & Huberman,1994) Wright maps, fit-misfit statistics, item discrimination statistics, instrument level information, item level information, item and person reliabilities, inter-rater reliability
To build a teacher learning progression to represent the progress of teachers' understanding of engineering design process To deliver a teacher PD program to emprically align with the learning progression	What levels do science teachers typically experience as they move from a novice to a more sophisticated of the engineering design process?	Design-based research (DBR) approach	Informative literature (books, and standard documents for upper anchor) Written assessments Item paneling Teacher logs Clinical interviews	Qualitative data analysis (Miles & Huberman,1994) Coding rubrics in line with each task of teacher logs and clinical interviews (Jin et al., 2013; Mohan et al., 2009) Triangulation of data sources, inter-rater reliability

3.3. Data Sources

The current study followed design-based research approach and used six data sources: a) written assessments, b) cognitive interview protocol, c) item paneling, d) teacher logs, e) clinical interview protocol, and f) “Science Teachers’ Attitudes towards K-12 Engineering Education Survey”.

a. Written assessments. Written assessments were used to gather initial information from in-service science teachers both on their attitudes, and on their knowledge of the engineering design process. In line with these goals, the written assessments included two parts. The written assessment questions can be examined in Appendix A. The first part was composed of questions related to teachers’ attitudes. This part contained seven questions. The second part was composed of four questions related to engineering design. The participant teachers filled in two parts of the written assessments; 11 questions in total. All questions were open-ended similar to learning progression studies that make use of written assessments (Jin & Anderson, 2012; Mohan et al., 2009). Collecting data at the very beginning of the study informed the levels of the first versions of the learning progressions.

The written assessments were implemented to 14 in-service middle school science teachers who filled in the questions online. A brief e-mail on the goals of the research and on collecting data with written assessments was sent to the participants together with the written assessment questions attached as a Word Document. Teachers were asked to send their responses within two days on the same Word Document. The teachers filled in the questions with their own personal opinions. For each teacher, filling in the 11 written assessment questions were reported to last for 15 to 20 minutes on average. For five of the teachers, whom data was collected at a later time than the other participant teachers (n = 9), the questions were put in a Google Form to make the process easier.

The questions on the first part; attitudes, were developed by the researchers. In order not to guide the respondents in any particular direction, asking broad questions was preferred. Some of the questions were inspired by the findings of the literature search; teachers' possible interest in improving themselves in K-12 engineering education and their ideas on possible value and importance they attach to K-12 engineering practices were tried to be captured. The questions on the second part; engineering design process, were influenced by the study of Schubert, Jacobitz, and Kim (2012). The authors studied the engineering design process knowledge of freshman engineering students. They collected data with five open-ended questions to assess engineering design knowledge: 1) What are the important components of the engineering design process? 2) What procedures and techniques do you know to search for and generate possible solutions? 3) Why is the design process iterative? 4) What methods for the evaluation of possible solutions do you know? and 5) Why do you document the design process? In order to collect data with the written assessments, two of these questions by Schubert et al. (2012) were directly included. The rest of the questions by Schubert et al. (2012) were too specific, such as the third one, including the iterative nature of engineering design. In total four questions were prepared and used in the second part of the written assessments.

The questions were refined with feedback from two experts. One of the experts was a professor of assessment and evaluation at a public university. The second expert was a PhD student of curriculum and instruction with experience on instrument development. Their comments and suggestions helped to develop the final version of the questions. Prior to their feedback, the questions on attitudes included questions directly asking for teachers' ideas on the contribution of engineering for the improvement of the society. However, it was recommended that such questions might guide the respondents to a certain direction. Another recommendation was about putting a question on the possible barriers or limitations teachers might face as they implement engineering practices in their instruction. For the written assessment questions on engineering design, a critical feedback was on putting a question where a simple case is given. It was recommended that such a question can better reveal teachers' understanding instead of directly asking their opinion. The questions on engineering design were piloted with a small group of pre-service science teachers (*n* = 2) to go over any unclear parts. This resulted in a revised version of the questions. An example revision was that, question three and four were combined at the time of pilot administration. However, it was observed that, having separate questions can bring about responses both on features and characteristics of engineering design as well as components and therefore steps of the engineering design process.

b. Cognitive interview protocol. Cognitive interviews were conducted mainly to refine the survey developed on teacher attitudes; "Science Teachers' Attitudes towards K-12 Engineering Education Survey" and also to refine the learning progression on teacher attitudes. The cognitive interview protocol can be examined in Appendix B.

With two PhD students taking a course that included cognitive interviewing strategies, pilot interviews were conducted. Following the pilot interviews, it was decided to include an introductory part in the interview protocol where the respondents could get used to the cognitive interview process. In preparation of the questions of the interview protocol, the following exemplary sources provided insights; Shafer and Lohse (2005), Sopromadze and Moorosi (2016), and Willis (2015). The final cognitive interview protocol included five parts; a) welcome, b) warm-up c) think-aloud questions, d) verbal probes, and e) closure questions. In total there were six think aloud questions, 16 verbal probing questions, and five closure questions. Not all questions in the cognitive interview protocol were used for each and every participant teacher. Instead, the cognitive interview protocol included options to help the interviewer. Due to the evolving nature of the cognitive interviewing, new verbal probes emerged in some cases, during the interview. The questions on the interview protocol were used interchangeably according to both the evolving nature of the interview and the thinking process of the interviewer. To set an example, if the respondent seemed to have difficulty in understanding the item, then the interviewer chose to ask: “What is the question/item is asking of you?”

Cognitive interviews were conducted with 10 middle school science teachers in total who participated to a STEM Education Workshop for nine days at a public university in Turkey. The interviews started with welcoming the participants. Following the welcome, a small practice was conducted to make the participants familiar with the procedure in warm-up. An unrelated case to the assessment task was chosen specially to gain practice for the think-aloud questions. The interviewer asked the participants, to recall the last time they visited a supermarket and try to imagine their visit as vividly as possible. First a general think-aloud phrase was given; “Tell me everything you remember”. This led the participants try to remember everything and speak about it; so the participants experienced a think-aloud at the very beginning of the interview. Think aloud questions within cognitive interviews is critical, because frequently questions are asked where the respondent is expected to tell everything about the item that he/she is thinking. This small think-aloud practice was followed by facilitating questions such as, how the smell was like, whether it was crowded, what people were buying in the supermarket. Following this small “warm-up exercise”, the interview started with the “think aloud questions” on the cognitive interview protocol. Again, not every question was asked for each and every item. Instead, the questions were used as an alternative to each other, providing a comfort zone for the interviewer. Also the choice of the question depended on both the item, and the response or lack of response of the respondent. For the next part; “verbal probes”, a commonly asked verbal probe was the first one; “What to you is X?” For example, when the respondent seemed to be thinking on “in-service training” in item1 in the survey, the interviewer asked questions to understand the personal meaning of “in-service training” for the respondent. Finally, “closure questions” were asked to capture any thoughts the respondents might have regarding the survey or the items in particular.

Again all optional closure questions were included in the interview protocol. During data collection, the same interview protocol was followed for all participants. Rapport was established at the beginning of the interviews by introduction of the goals of the study. The interviews were audio-recorded which were later transcribed verbatim. During each interview, the interviewer took some notes. These notes were helpful in the data analysis process.

c. Item paneling. The goal of item paneling was to receive feedback from an expert audience on the learning progressions to make revisions and to increase their quality. In total, two item panelings were conducted. The first one was on the learning progression and its associated survey on teacher attitudes. In total, one expert on developing instruments and three experts on guidance and psychological counseling attended to this item paneling. The second item paneling was on the learning progression on teachers' understanding of the engineering design process. This time two experts on curriculum and instruction and one expert on STEM and engineering design participated. Field notes were taken during each item paneling which were later examined for recommendations on how to refine the two learning progressions and the survey on teacher attitudes. Participants of the item panelings differed based on the content of the learning progression. Inclusion of professionals, academics, and researchers in relevant areas are recommended for item paneling (Wilson, 2005). Panelists were supplied with the learning progressions, and the survey for the case of the item paneling on teacher attitudes. Item panelings started with a brief presentation on the learning progression and the goals of the study. Later a discussion took place making sure each panelist can contribute to the discussion in productive ways (Wilson, 2005). This discussion resulted in various ideas and comments. During the item panelings, to the fact that most panelists were not familiar with the learning progressions approach, the approach itself was clearly explained in a step-by-step manner. Each item paneling lasted around half an hour.

d. Teacher Logs. The purpose of collecting data with teacher logs was to elicit teachers' thinking on the engineering design process and to see the commonalities and differences in their understanding; ranging from novice to more sophisticated. The teacher logs were administered to 30 in-service middle school science teachers who participated to the teacher PD program implemented at Phase 2 of the current study (see Figure 8). The tasks on the teacher logs were similar to the ones in the clinical interview protocol. The final version of the Teacher Logs can be examined in Appendix C.

Teacher logs was composed of different tasks as was the case for the clinical interviews. There were three tasks created parallel to the tasks in the clinical interview protocol. These tasks were created by the researcher based on; a) the content of the teacher PD program implemented at Phase 2 of the methodology framework of the study (see Figure 7), and b) the second version of the learning progression on engineering design process (see Table 4). There were several questions that corresponded to each task. The development of the tasks went through revisions following expert opinion. The experts that provided improvements on the tasks were two PhD students both of whom had a B. S. in science education. Prior to taking feedback, the first two tasks were merged as Task 1 however, it was suggested to include separate tasks to reflect engineering design process model, its features and engineering design process steps separately. Another feedback was on decreasing the number of questions. Before the expert opinion, the Teacher Logs included five tasks. However, it was recommended that those teachers would be tired at the end of both first and second days of the PD program. In order to get more useful data, the number of tasks was kept at three. More information on the administration of teacher logs were presented in the following sections.

The first task was on engineering design process models and the goals and features of engineering design process. Teachers responded to questions on the goal and structure of the engineering design process. They also reported the characteristics they know on the engineering design process such as being iterative. The second task was on engineering design process steps and concepts. Some concepts that were underlined were criteria, constraints, and tradeoffs. Teachers were asked to report the engineering design process steps they know and put them in order. In order to make the task easier who still have no idea on criteria, constraints, and tradeoffs, the questions included prompts that reminded teachers of the engineering design task they completed that day. The third and final task was on evaluating a complete engineering design process. Teachers were expected to consider the strengths and weaknesses of their own implementation of the engineering design process at the teacher PD program. Teachers were guided to think of the engineering design task they completed. Teachers reflected their knowledge on the engineering design going over their own design team's performance for the first day's engineering design challenge; designing a wind turbine.

Easier questions on the teacher logs were implemented at the end of the first day of the teacher PD program implemented at Phase 2 of the methodology framework of the study (see Figure 7), and the second part of the teacher logs were filled in at the end of the second day of the teacher PD program. This was based on two rationales. Firstly, teachers could be exhausted with all the questions on the teacher logs completing them on one day. Secondly, on the first day, easier questions on the teacher logs were asked since they were still in the learning process. For the higher levels items, teachers could only respond to when they fully experienced the PD program. The questions required a more sophisticated thinking. The implementation of the Teacher Logs lasted approximately 20 minutes on each day of the teacher PD program. Therefore, administration of the whole Teacher Logs for two days lasted for 40 minutes.

e. Clinical Interview Protocol. Clinical interviews were conducted to elicit teachers' thinking on the engineering design process as was the case for the teacher logs. The interviews were conducted with 10 in-service middle school science teachers selected among the 30 teachers who participated to the teacher PD program implemented at Phase 2 of the current study. The results shed light on the differentiations between teachers who had a naive understanding and who had a more sophisticated understanding of the engineering design process. In order to ensure capturing such differentiations, participant teachers of the clinical interviews were deliberately chosen to represent a variety of understanding levels of the engineering design process. Following such a sampling, and making teachers elaborate on their understanding through a clinical interview fit the purpose of revealing a range from novice to a more sophisticated understanding. So, the participants of the clinical interview were selected to reflect variance among understanding of the engineering design process. This was crucial to receive data to work on all levels of the learning progression; from lower levels to the higher levels.

The clinical interview protocol composed of both think aloud questions and verbal probes. During the interviews, the interviewer first asked the respondents to talk about anything that comes to their minds to answer the question or reply to the task. This exemplified a think-aloud process. Following that, the interviewer used verbal probes written on the interview protocol to make sure teachers did not lose focus and kept thinking on the content of the question. The clinical interview protocol contained three tasks (see Appendix D). These tasks were identified and developed based; on a) the content of the teacher PD program implemented at Phase 2 of the methodology framework of the study (see Figure 7), b) the second version of the learning progression on engineering design process (see Table 4), and c) the following sources serving as guides in particular; Atman et al. (2007), Hsu et al. (2010), Jin et al. (2013), Mohan et al. (2009), and Mosborg et al. (2005).

The development of these tasks went through revisions following expert opinion and a small piloting. The experts that provided improvements on the tasks were two PhD students studying on curriculum and instruction. Both of them had a B.S. degree in Science Education. To set an example, the first two tasks were merged as Task 1 however, it was suggested to use separate tasks as engineering design process model and engineering design process steps and concepts to better facilitate teachers' thinking. As a second example, the experts recommended to revise the tasks slightly so that each task reflected a different level of understanding. This meant creating tasks from easy to difficult. This suggestion was used to revise the interview protocol. This was very helpful information to facilitate teachers' thinking processes at different difficulty levels. The two experts also helped with minor revisions on the language, wording and format of the clinical interview protocol.

Next, a small piloting with three fourth year undergraduate students in the program, Science Education was conducted. Initially the clinical interview protocol included six tasks. However, during the pilots, it was experienced that the interviews took approximately an hour to complete and the respondents were too tired to complete the sixth task. Therefore, the sixth task that asked teachers to apply the engineering design process to a case was removed from the interview protocol. Another revision decided with the pilotings was to remove the last part of Task 3. This second part of this task also attempted to reveal how novice and expert teachers differ on their conceptions and misconceptions. In total, 20 statements inspired by the study of Oehlberg and Agogino (2011) were presented and teachers were expected to select a few ones that they found to be the most critical on engineering design. However, during the pilotings, it was observed that the results differed too much to reach a conclusion. In addition, the participants seemed to find the list too long and without concentrating only chose some statements for the sake of choosing. A last point noticed was that, the data coming from this task was could be similar to the data coming from the remaining tasks. With this realization, this part was completely removed. Some example statements removed from this task were; “Design is what distinguishes engineering from science”, “Design is iterative”, and “Constraints are critical components of the engineering design process”.

The first task was on engineering design process model. First the teachers who were in-service middle school science teachers were asked to draw a model of the engineering design process. Then the interviewer asked verbal probes on each step drawn and the general logic and structure of the model. This was followed by a question on different engineering design process models. The second task focused on the engineering design process steps and concepts. With verbal probes, each step on the engineering design process step was revisited for their relationship to each other and also for their relation to the whole model. Especially the engineering concepts criteria, constraints and tradeoffs were elaborated on with both think aloud and verbal probes.

The purpose of the third task was to understand the differences between novice and expert teachers in how they evaluate a complete engineering design process (see Figure 9). For this task, at first, teachers were presented with the complete engineering design example by Cardella, Hsu, and Ricco (2014). Teachers were first asked think aloud and report anything they consider as they examine the figure. Then the interviewer used verbal prompts to enable teachers to evaluate the process. Lastly, the complete engineering design rubric by NASA let it glide was shown to the teachers. They were asked to evaluate the figure based on the rubric. This was especially expected to be performed especially by the expert teachers. The second part of the same task highlighted the engineering design experience of the teachers during the teaching intervention; the PD program. Teachers were guided to think aloud and they responded to several verbal probes on their performance during the PD program. Teachers were forced to examine and evaluate their performance with their design team considering the engineering design process steps and engineering concepts. The interviews were audio-recorded which were later transcribed verbatim. During each interview, the interviewer also took some notes. These notes helped with the data analysis process. Completing the interviews with each participant took around 35 minutes. For three of the participants, the clinical interviews lasted more than an hour.

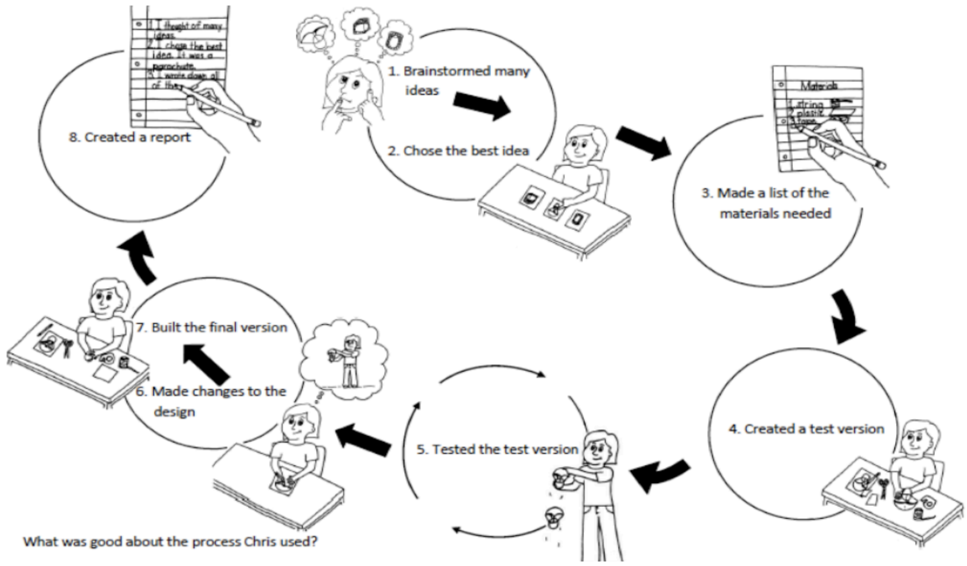


Figure 9. Part of third task (Cardella, Hsu, & Ricco, 2014, p. 4)

f. Science Teachers' Attitudes towards K-12 Engineering Education Survey. The "Science Teachers' Attitudes towards K-12 Engineering Education Survey" was developed as the associated instrument of the learning progression on science teachers' attitudes towards K-12 engineering education. Developing such associated data collections instruments is a method to ensure empirical validation of the learning progressions. The survey items associated with the learning progression were aimed to document how science teachers' attitudes differ from negative attitude to positive attitude. The literature included examples of developing learning progressions with their associated instruments; Alonzo and Steedle (2009), Nguyen and Griffin (2012), and Mahat (2008). Establishing a theoretically and empirically supported alignment between the learning progression levels and the survey items makes it possible to better map the respondent teachers on a continuum ranging from negative attitudes to positive attitudes.

The survey was implemented at the teacher PD program at Phase 2 of the methodology framework of the study (see figure 7). This was the second version of the survey (see Table 4) which consisted of 22 Likert-type items (see Appendix F).

The respondents were the 30 middle school science teachers who participated to the teacher PD program implemented at Phase 2. The items had five response categories ranging between strongly disagree and strongly agree.

The items of the first version of the survey was developed based on a through literature search and results of the written assessments on teacher attitudes. Later the survey was revised with results of the item paneling and cognitive interviews. Finally, following the administration of the survey at the teacher PD program at Phase 2 of the methodology framework of the study, a statistical analysis was conducted to analyze the data. Final refinements were completed at Phase 3 of the methodology framework of the study. To sum up, the current study presented two versions of the survey. These versions were based on literature search, written assessments, item paneling, and cognitive interviews. Lastly following the implementation of the survey at teacher PD program and statistical analysis of data with the statistical program, R studio, recommendations on a possible third version of the survey were provided.

The "Teachers' Attitudes towards K-12 Engineering Education Survey" was first filled in by the teachers one week prior to the teacher PD program. Then the survey was implemented on the last hour of the teacher PD program for the second time. This technically resulted in 60 different cases. During the data analysis, they were treated at 60 different respondents. The probability of teachers' mostly having positive attitudes at the closure of the PD program was the main reason for this type of implementation. It was assumed that the teachers were already motivated to learn about K-12 engineering education. Therefore, it was decided as a better option to also gather pre-test data as well to be able to capture a wider range of teacher attitudes, from negative to positive.

3.4. Participants

The necessary permission to collect data was taken from the Human Subjects Ethics Committee at Middle East Technical University to. Participants of the study remained confidential and they all volunteered to be a part of the study. Participants were informed about the goals of the study. The sampling procedures differentiated based on two aspects: a) to represent a variety in terms of the levels of the learning progressions, and b) to access the most useful results within feasibility concerns. Accordingly, two sampling strategies were followed; convenience sampling and purposive sampling. Table 6 presented the participants of the study. For some of the research steps (see Table 4), participants were included due to their convenience, a certain group of people were chosen because they were available. “The obvious advantage of this type of sampling is convenience” (Fraenkel, Wallen, & Hyun, 2012, p. 99). Use of purposive sampling was also critical for the study to be able to capture a profile reflecting all levels of the learning progressions.

With purposive sampling strategy, the interest was on including a sample that can provide the essential data needed instead of people who are just available (Fraenkel et al., 2012). Each step of the research required participants coming from different understanding, and level of expertise and/or experience.

Information on the participants of; a) written assessments, b) item paneling, c) cognitive interviews, d) teacher professional development program, e) Teacher Attitudes towards K-12 Engineering Education Survey and teacher logs together, and f) clinical interviews were explained separately in Table 6.

Table 6. *Participants of the Study*

	Participants	
	To develop a learning progression and survey on attitudes	To develop a learning progression on engineering design process
Written assessments	14 middle school science teachers	
Cognitive interviews	10 science teachers that participated to a STEM Education Workshop	NA
Item paneling	Experts on developing instruments (n = 1), and on guidance and psychological counseling (n = 3)	Experts on curriculum and instruction (n = 2), STEM & engineering design (n = 1)
Implementation of a Teacher PD program at Phase 2 of the study	30 middle school science teachers coming from various cities in Turkey	
Teacher Attitudes towards K-12 Engineering Education Survey	30 middle school science teachers that were participants of the teacher PD program implemented at Phase 2 of the study	NA
Teacher logs	NA	30 middle school science teachers that were participants of the teacher PD program at Phase 2
Clinical interviews	NA	10 middle school science teachers selected among participants of the teacher PD program implemented at Phase 2

a. Written assessments. The written assessments were conducted with 14 in-service science teachers working in middle schools in Turkey. The sampling strategy included both convenience sampling and purposive sampling. Teachers were selected among the ones who had experience with K-12 engineering activities (see Table 7). All teachers were accessed through personal networking who were willing to answer the written assessment questions.

Table 7. *Participants of Written Assessments*

Gender	City teacher lives and teaches in	Accessing teachers	Experience with engineering
Female (*n* = 10), male (n = 4)	Ankara, Istanbul, and Bursa, Turkey	All through convenience sampling; majority through personal networking (*n* = 9), remaining teachers (*n* = 5) through researcher's participation to a STEM Education Program as a trainer	Most teachers had experience on engineering and STEM activities either implemented in class or attended a training before (*n* = 9), some just completed a STEM education program (*n* = 5)

In total, five of the participants were teachers who participated to a STEM Education Program. It was a three-day STEM Education Program provided by a public university in Turkey in July, 2016 with the participation of 27 science teachers. The researcher of the study was a trainer at the STEM Education Program. The five participant teachers were mainly selected based on their convenience to the researcher. Secondly, as the researcher made observations, these five teachers were recognized to be more willing to contribute to the study. These five teachers were the ones that data was collected at a later time compared to the rest of the group (*n* = 9). One week following their participation to the STEM Education Program, the written assessment questions were filled in by five teachers in a Google Form, in order to have an overall idea on their attitudes and knowledge of engineering design process.

The teachers who were not accessed through the STEM Education Program (*n* = 9) were acquaintances of the researcher who were known to have experience on STEM and engineering activities. They were mainly accessed following a personal networking strategy. They all volunteered to fill in the written assessment questions.

b. Item paneling. During item paneling, each panelist was provided with the learning progressions, and "Science Teachers' Attitudes towards K-12 Engineering Education Survey" for the item paneling on teacher attitudes. Both convenient sampling and purposive sampling procedures were followed in accessing the participants of the item paneling. The panelists were chosen among the ones who had an expertise on attitudes, STEM and engineering design, and curriculum and instruction or related fields in order to obtain useful feedback (see Table 6).

There were two item panelings conducted; one for the learning progression on teacher attitudes and its associated survey; “Science Teachers’ Attitudes towards K-12 Engineering Education Survey”, and the other one for the learning progression on teacher engineering design process understanding. The participants of the item paneling on teacher attitudes included experts on developing instruments (*n* = 1), and on guidance and psychological counseling (*n* = 3). These experts were selected based on their convenience. The expert in STEM and engineering design was an assistant professor at a public university in Turkey. For the remaining three experts, they were all research assistants and PhD students at guidance and psychological counseling program at a public university in Turkey. The participants of the item paneling on teacher understanding of the engineering design process included experts on curriculum and instruction (*n* = 2), and on STEM and engineering design (*n* = 1). These experts were again selected based on their convenience. Among the experts, one of them was a professor at a public university in USA. The learning progression and the instrument was provided to her online separate from the rest of the panelists. The rest of the panelists were PhD students and research assistants at the department of Educational Sciences and Elementary Education at a public university in Turkey.

Comments and recommendations of the experts resulted in revisions to the two learning progressions and the survey on teacher attitudes. Only to improve the items of the survey; “Science Teachers’ Attitudes towards K-12 Engineering Education Survey”, additional expert opinion was taken from two experts. Both of these experts were faculty members who conducted research on STEM education. They were working in two different public universities in Turkey, one of them as a professor and the other one as an assistant professor.

c. Cognitive interviews. Conducting cognitive interviews mainly aimed to refine the "Science Teachers' Attitudes towards K-12 Engineering Education Survey" and create its second version. The results of the interviews also created revisions to the learning progression on teacher attitudes. Participants were accessed through purposive sampling and convenience sampling. For cognitive interviews where the goal was to improve the quality of an assessments instrument, expectation of a convenient sample that has more knowledge on the topic of the instrument is selected (Ackermann & Blair, 2006). Overall, having 10 participants is considered sufficient for one round of cognitive interviewing (Willis, 2015). Information on the participants can be found in Table 8.

Table 8. *Participants of the Cognitive Interviews*

Gender	Cities teacher lives and teaches in	Age range
Female (*n* = 6), male (*n* = 4)	Çorum, Hatay, Izmir (*n* = 2), Usak, Karaman, Giresun, Kocaeli, Kayseri, Istanbul	Between 20-25 (*n* = 3), between 26-30 (*n* = 2), between 30-40 (*n* = 4), and one teacher was 43 years old

The cognitive interviews were conducted with middle school science teachers (*n* = 10) who participated to a STEM Education Workshop for nine days at a public university in Turkey. As the researcher was a guide in this Workshop, teachers were selected for their convenience. In total, 30 teachers participated to the STEM Education Workshop. To select the participants of the cognitive interviews, two criteria had to be followed purposefully: a) teachers who had an overall understanding of the K-12 engineering education, and b) teachers who experienced application of engineering design challenges. The interviews were conducted towards the end of the Workshop; on the last three days of the Workshop. The main reason was to wait so that teachers increased in their understanding and experience on engineering design. Among the 30 teachers, 10 of them were selected with personal observations during the Workshop. In addition to the abovementioned two criteria, teachers who seemed more willing to share their knowledge and experience were selected. Selected teachers were working in public schools in different cities in Turkey which represented a wider range of ideas regarding different contexts. Also teachers were selected to reflect different age groups to represent experience in teaching.

d. Teacher PD program implemented at Phase 2 of the methodology framework of the study. In selecting the participant teachers to the teacher PD program, certain criteria were followed. The major goal of following particular criteria was to result in a variation of levels to better represent the learning progression on understanding of the engineering design. No certain criteria were used to select teachers to represent different levels in terms of their attitudes. It was assumed that teachers would already have variety in terms of their attitudes.

The criteria followed to select teachers to the teacher PD program were: a) level of participation to STEM and/or engineering design teacher PD programs before, b) level of knowledge on engineering design process, c) gender, d) city in Turkey working as a teacher, e) experience in teaching, and finally f) school type as public or private. In all of the criteria presented above, a variety was tried to be reached. The first two criteria were directly related with seeking for a variety among participants on their understanding of engineering design; ranging from a novice understanding towards a more sophisticated understanding. This selection could enable creation of the learning progression on engineering design more effectively. In order to select teachers representing different levels of the learning progression frameworks; such criteria were important. Typically, in learning progression development studies, participants are selected to reflect different levels in the learning progression framework; such as from grade levels 6, 8 and 10 (Neumann et al., 2013). In the case of the current study, the possible differences between teachers' knowledge of the engineering design process was reflected by selecting them with distinct knowledge levels on engineering design process. This type of selection was essential for the validity of the learning progression levels. The remaining criteria presented were important in order to have a heterogeneous group that could learn from each other's experiences. These criteria were critical to create a success for the learning climate of the teacher PD program. A noteworthy point was in selection of teachers for the two of the criteria; school type and city, public school teachers and teacher working in small cities were prioritized. Because in small cities in Turkey teachers cannot always access to qualified teacher PD programs.

The teachers were accessed through advertising the teacher PD program with posters in schools, Faculties of Education, and in social media platforms; Facebook and Twitter. A particular webpage was developed to advertise the teacher PD program and to provide information on its details (see https://tasarlayapogren.wordpress.com). Appendix E included a visual of the Webpage. The Webpage contained information under five links which were: a) content of the PD program, b) designers and trainers of the PD program, c) contact the program designers, d) poster of the PD program, and e) application to the PD program. An application form, which was prepared as a Google Form was later inserted to the webpage. Through this form, science teachers could make their online applications to the PD program. Three of the questions on the Google Form were on personal contact information in line with the selection criteria presented above. Among these questions two of them aimed to categorize teachers on their understanding and experience on engineering design. One of these questions was a prompt to receive knowledge on engineering design process. The other questions asked teachers to report their previous participation to STEM activities/seminars/workshops. To summarize, the prompt on engineering design process, and teachers experience regarding participation to STEM training before, were the two criteria in selecting teachers so that they reflected low, middle and high levels of the learning progression. The rest of the questions on the application form were asked in order to gather information on the profile of teachers such as; city, school type, and years of experience. With information gathered via the application form, an initial profile of the applicant teachers was created as an Excel sheet. The application period was for two weeks in total. During this period, 320 science teachers applied to the program. The number of teachers who responded to this prompt other that as “I don’t know” or who left it as blank was 193, so remaining was 127. The responses from 127 teachers were descriptively analyzed in order to understand the differences between teachers’ understanding of the engineering process. This descriptive analysis resulted in selection of teachers according to a variety in their engineering design understanding and in categorization of the selected teachers. Table 9 presented information on this categorization that helped select the teachers. As can be noticed in Table 9, first two criteria applied to select teachers to the teacher PD program was influential in creation of the three categories of teachers. These criteria were: a) level of participation to STEM and/or engineering design teacher professional development programs before and b) level of knowledge on engineering design.

With their responses in their application form, teachers could be categorized. These categorization of teachers was critical for their representation of learning progression levels in terms of understanding of engineering design. Detailed information on the teachers who participated to the teacher PD program can be found in Table 10. Their categorization as novice, intermediate, and novice was again presented in this table.

e. Science Teachers’ Attitudes towards K-12 Engineering Education Survey and Teacher Logs. The survey and the Teacher Logs were completed by all teachers participating to the teacher PD program implemented at Phase 2 of the methodology framework of the study. The participants of both the survey and the teacher logs included the 30 science teachers described in Table 10. However, for the teacher logs, at some point data was analyzed among 29 teachers because data coming from one of the teachers included many missing responses.

Table 9. *Categories of Teachers*

Category of teachers	Description of category	Example responses to the prompt on engineering design
Expert	Teachers who have participated to more than one STEM training before. Teachers who implemented engineering activity in class before. Teachers who could report on majority of engineering design process steps, features and/or concepts correctly.	…..states almost all steps correctly…..it is an iterative process, we go back to beginning and make revisions…..marketing is part of the process, among many solutions the best one is selected…
Intermediate	Teachers who participated to one STEM training before. Teachers who could report on some of engineering design process steps, features and/or concepts correctly.	*……states some of the steps correctly…..problem is at the focus for planning…there is the engineering design process as a plan….*
Novice	Teachers who have never participated to a STEM training before. Teachers who had no knowledge related to engineering design	*…..within engineering design process, there is a problem, there are experiments and tests……..*

f. Clinical interviews. In total, 30 middle school science teachers participated to the teacher PD program. Among the participant teachers 10 of them were interviewed within the week following the teacher PD program. These 10 teachers were selected based on: a) their location for feasibility purposes to access, and b) the variety in terms of their categorization on engineering design process understanding. The categorization in Table 9 was used in selection of the teachers. With consideration of the two criteria stated above, three novice teachers, four intermediate teachers and four expert teachers were selected. Representing variety in levels of understanding of the engineering design was crucial in order to see the differences in thinking process and to be better able to refine the learning progression.

Table 10. *Participants of the Teacher PD Program*

Gender	Experience in teaching	School type	City	Categorization for understanding of engineering design
Female (*n* = 17), male (*n* = 13)	Less than 5 years (*n* = 10), 5 to 10 years (*n* = 11), more than 10 years (*n* = 9)	Private (*n* = 9), public (*n* = 21)	From Ankara and Istanbul (*n* = 14), other cities (*n* = 16) (e.g. Amasya, Bursa, Van, Sanlıurfa)	Novice (*n* = 10), intermediate (*n* = 10), expert (*n* = 10)

Among the novice group of selected teachers (*n* = 3), two of them lived in Ankara and one lived in Istanbul. In the intermediate group (*n* = 4), two lived in Ankara, one lived in Konya, and one lived in Eskişehir. In the expert group (*n* = 3), two lived in Ankara, and one lived in Adıyaman. For the three teachers who lived out of Ankara and Istanbul, who were difficult to access, clinical interviews were conducted through phone interviews.

3.5. Conceptual Framework of the Teacher PD Program

The teacher PD program implemented at Phase 2 of the methodology framework of the study (see Figure 7) was conceptually based on; a) the second version of the learning progression on engineering design process understanding, b) the core elements of teacher PD programs created and presented in Figure 2, and c) descriptions of the engineering design process as presented in Chapter 2; Review of the Literature (see Table 4).

Accessing teachers with knowledge on engineering design process can be quite challenging due to most teachers' their lack of experience and knowledge in the Turkish context. Therefore, delivery of a teacher PD program enabled having teachers who have a high level of understanding of engineering design process as they complete the teacher PD program. It was decided to deliver a teacher PD program for the current study to: a) have teachers reflecting a range of engineering design understanding from novice to more expert, b) have an instructional context where the learning progressions can be empirically refined, and c) to contribute to teachers' improvement in K-12 engineering education. Teaching interventions are one effective way of validating learning progressions. As Alonzo and Steedle (2008) suggested, learning progressions should present instructional environments to investigate the progressing variable closely. The initial versions of the learning progressions should be detailed enough to guide the PD program (Krajcik et al., 2012). It can be concluded that the levels of initial learning progression on engineering design understanding was influential in terms of the conceptual framework of the PD program. An example on this influence was inclusion of aspects of engineering design process as it appeared on the levels of the initial versions. These aspects were different models of engineering design, conceptions on engineering design, the engineering design concepts; criteria, constraints and tradeoff and steps of the engineering design process.

To continue, the core elements on teacher PD programs (see Figure 2) on K-12 engineering education helped with the design of the PD program conceptually. Each core element was examined and constructed in detail. To set an example, the engineering design activities of the PD programs as a core element, specifically focused on steps of the engineering design process, identifying constraints and criteria, problem identification and explaining tradeoffs. As a second core element, when the thematic structure is considered, overall the theme of the teacher PD program as science content was renewable energy and wind energy, and the theme as an engineering strand was mechanical engineering and aerodynamics engineering. This is a highlighted topic for middle school students in Turkey to comprehend as it is addressed in Science Program in Turkey (MoNE, 2012). It is a major content included NGSS (NGSS Lead States, 2013) as well. As presented in Table 2, many teacher PD programs on K-12 engineering education focused on the energy topic. NGSS (NGSS Lead States, 2013) addressed the energy content "Energy and matter: Flows, cycles, and conservations" as one of the Crosscutting Concepts. For mathematics, the PD program has a focus on "Scale, Proportion and Quantity: as a

Crosscutting Concept (NGSS Lead States, 2013). For the Mathematics Education Program in Turkey (MoNE, 2013), geometry, measurement, and data analysis were important aspects that were addressed in the PD program. For technology content the PD program included the four competencies reported in the Information Technologies and Software Program in for Middle Schools Turkey (MoNE, 2013). These were; a) technology literacy, b) construction of knowledge and collaboration, c) problem solving and design of authentic products, and d) communication and share of information.

For the same core element, thematic structure, having a strand of engineering was found critical. engineering design as a context to merge the three disciplines; science, technology and mathematics, mechanical engineering and aerodynamic engineering were selected as the strands of engineering focus. This was mainly due to the fact that, the science content Renewable Energy and Wind Energy selected for the PD program necessitated the selection of these strands of engineering. This alignment between the selected science content and the strand of engineering as mechanical was confirmed with the materials developed by Museum of Science, Boston (Cunningham, 2009). As the engineering experts that collaborated for the PD program suggested, aerodynamic engineering was also included as in real life mechanical and aerodynamic engineers' work on wind energy together. All activities centered on two engineering disciplines; mechanical engineering and aerodynamics engineering.

As another core element, engineering subject matter knowledge was considered. The teacher PD program included interactive lectures, activities and discussions on K-12 engineering education, engineering design process, nature of engineering, practices of engineers and how engineers and their products interacts with the society, similarities and differences of engineering and science/scientific inquiry, similarities and differences among different engineering design process models, and engineering and technology in everyday items were aspects of engineering subject matter knowledge covered by the PD program.

Collaboration with engineers is another critical core element for teacher PD programs. The researchers collaborated with a team of engineers working at METUWind, Middle East Technical University. METUWind is a center for wind energy where eight engineering departments in METU collaborate. Their research projects mainly focus on wind potential assessment, wind turbine aerodynamics and wind turbine blades. From METUWind, four engineers took part in the design and delivery of the PD program. This team of engineers included two mechanical engineers, one aerodynamic engineer, and one environmental engineer. The educators of the program included academics from Faculty of Education, engineers and research assistants. This enabled bringing science teachers, university faculty experienced on STEM education and engineering pedagogy, and engineers together to create a fruitful learning environment. This kind of learning environment provided the participants with a rich professional development experience (Pinnell et al., 2013).

There were two engineering design challenges in the PD program where teachers worked on engineering design cycle in design teams. Both of the design challenges were based on a real-context linked to the science and engineering themes of the PD program. A field trip was organized to the engineering labs of METUWind. The team of engineers introduced their workplaces to the teachers. During the PD program, teachers were expected to work in design teams as they work on their engineering design. At the end of each design challenge, the design teams presented their refined designs to the class. As a last core element, the PD programs are better productive when they are designed to include follow-ups along with the face-to-face workshop. The current study only included the face-to-face workshop due to feasibility concerns.

A last aspect for developing a conceptual framework, the design of the PD program drew mainly from the materials and structures of Museum of Science; Engineering is Elementary Units (Cunningham, 2009) and the “framework on elements of a quality engineering education curriculum units and activities” (Moore et al., 2014b, p. 9). These elements were: a) having a meaningful purpose and an engaging context,

b) having all learners participate in an engineering design challenge with a relevant purpose, c) having opportunity to redesign, d) including appropriate science and mathematics content, e) teaching with student-centered pedagogies, and f) improving teamwork and communication. To keep the context meaningful and engaging, national and international issues were underlined during the presentations and discussions of the PD program. The two engineering design challenges in the program were tied to societal problems as well. Both of the engineering design challenges reflected the science content of the PD program; energy sources, renewable energy and energy transformation. Overall, the above mentioned elements were focused on in the implementation of the teacher PD program.

3.5.1. Implementation of Teacher PD Program

The teacher PD program was a two-day face-to-face program. It was delivered on a weekend to ensure the participation of teachers since during the weekdays teachers were working in schools. Teachers participated to the program activities beginning at 9 a.m. and ending at 5 p.m. for each day. Face-to-face workshop is the most widely used form of teacher professional development (Cejka et al., 2006; Chin et al., 2011; Duncan et al., 2011). Workshops commonly include exposing K-12 teachers to basic engineering concepts and examples, reinforcing this instruction with hands-on experiences and providing materials and resources to share with their students (Jeffers et al., 2004). In the PD for the current study, interactive lectures, activities, engineering design challenges, discussions, field trips took place. The trainers of the PD program included five researchers and engineers working at METUWind, four engineers who took part in panel and evaluation in design challenge products, and four guides experienced on K-12 engineering education and STEM activities. Photos helpful in describing the context of the teacher PD program can be found in Appendix E. Details on the outline PD program was presented in Table 11.

The *context integration model* by Moore et al. (2014a) necessitated engineering design as the core; the main context with support from the three disciplines; science, mathematics and technology. In the engineering design challenges, this main idea was followed. Participant teachers were exposed to two engineering design challenges that integrated engineering design with the scientific concepts of energy conservation, renewable energy and wind energy. For the first engineering design challenge, teacher design teams designed wind turbines. For the second engineering design challenge, teacher design teams designed a Lunar Vehicle. In both engineering design challenges, teacher design teams presented the prototype of their designs and also their refined and final designs.

The design challenges were based on an engaging and real-world context. Teachers were expected to develop their knowledge and understanding on energy sources, renewable energy, energy conservation, wind energy, geometry and calculation, data analysis, technology literacy through the engineering design challenges, small activities, discussions and presentations. Teacher design teams were expected to follow the engineering design process steps as they went through the challenge. All activities revolved around engineering design process, nature of engineering, and how engineers work, science content, mathematics content, and technology content selected. With exposure to all of these activities, teachers were provided teachers with opportunities to recognize and understand engineering in real life. Overall, teachers were able to comprehend a broad perspective of the nature and practice of engineering (Duncan et al., 2011).

The main sources that guided the engineering challenges and other activities were the units chosen from Engineering is Elementary (Cunningham, 2009), documents on design challenges prepared by Lawrence Hall of Science at University of California, Berkeley, and NASA’s BEST Activity Guides (NASA, 2012).

Table 11. *Outline of the Teacher PD Program*

Day 1
Registration and welcome **Introductory presentation: STEM Education** Introduction to STEM education and engineering design **Ice breaking activity** Participant teachers get to know each other with a small activity **Presentation: Introduction to engineering** Work of mechanical, aerospace and aerodynamic engineers. Nature of engineering and methods of engineers, engineering design. Science connections of the PD program: energy, wind energy and windmills **Fieldtrip and demonstrations** Engineering labs, introducing the tools and workplace of engineers **Panel: Who are engineers** Connections between real life and engineering, engineering and society, engineering and education, how engineers design and use engineering design process, problem solving **Engineering design challenge** Designing a windmill **Implementation of Teacher Log part 1**
Day 2
Interactive presentation and discussion Engineering design cycle, engineering design models, Engineering concepts **Exhibition with Station Technique** Exploring five different designs **Engineering design challenge** Designing a Lunar Buggy Car **Implementation of Teacher Log part 2** **Evaluation and closure of the PD program** Comments and recommendations, big group discussion

At the beginning of the first day, during the interactive introductory presentation, the trainers of the PD program provided an introduction; STEM education, K-12 engineering education its short history, pedagogical approaches, connections to science, mathematics and technology. Afterwards, a presentation as introductory to engineering was provided by one of the engineering faculty members at Middle East Technical University. This presentation was followed by techers' comments and questions to the presenter. Teachers had the chance to learn the nature of engineering from an experienced engineering and a faculty member at the same time. Next, a field trip to the engineering labs of METUWind took place. METUWind is a research center where engineers from different disciplines at Middle East Technical University collaborate on research projects. During the field trip, the engineers introduced their tools, work methods and workplaces. “The panel: Who are engineers?” included four engineers as panelists and one moderator who was experienced on K-12 engineering education. Engineers shared their experiences, their methods and tools in their profession. Engineering as a discipline for the improvement of the society and for solving the global challenges were discussed. Teachers volunteered to ask questions at the question and answer session. The teachers brainstormed about the nature of engineering, process of design, and the connections of design and engineering with the real problems of the society. The first day ended with the engineering design challenge; design of a windmill where teachers worked in design teams. After they got feedback to their prototypes, they refined their designs. The engineers were active during this process as well. They monitored the teacher design teams and they gave feedback to them on their designs and how they follow the engineering design process. At the end of the day, each design team presented their final designs. A jury composed of two engineers and two STEM education experts evaluated the final designs and discussed the weaknesses and strengths.

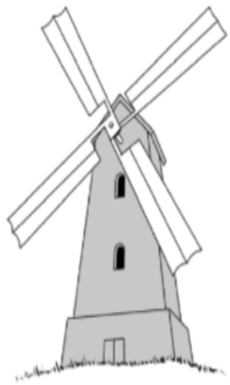
The second day began with an interactive presentation on the details of the engineering design process. The similarities and differences of various engineering design process models were discussed. Some of the models and related materials were prepared by NGSS (NGSS Lead States, 2013), Massachusetts Engineering Framework (Massachusetts Department of Education, 2006), and Engineering is Elementary units and materials (Cunnigham, 2009). Following this, an exhibit with five demonstrations of engineering design examples was conducted. The five strands included the engineering sets of Vernier; Windkit, five different engineering design products, technologies teachers can use during design and evaluation stages, wearable technology, and engineering design examples on energy conservation. This exhibit was especially important for the teachers to be familiar with technological tools to integrate engineering to their instruction. The Vernier Windkit set (see Appendix E) contained many examples of energy sources and energy conservation demonstrated with sensors and probes. The Vernier Windkit set was an excellent technological tool to collect, analyse and present data. The day continued with the second engineering design challenge of the PD program; design of a Lunar Buggy car. Teachers once again worked in their design teams. After teachers got feedback to their prototypes, they tested their designs again and made necessary revisions. Each design team presented their final design of Lunar Buggy Cars. Teachers had the chance to receive feedback from the engineers and researchers from METUWind on their engineering design process practice performances and on their final designs.

At the end of each day, teachers filled in their Teacher Logs. In addition, on the end of second day, teachers filled in "Science Teachers' Attitudes towards K-12 Engineering Education Survey" for the second time. The second day ended with an overall evaluation of the teacher PD program. Figure 10 presented visuals from the documents teachers used as they worked on the engineering design challenges. Appendix G presented the full version of the documents teachers used during the teacher PD program.

The full version of the documents in Appendix G included detailed information on the two engineering design challenges that the techer design teams worked on. As can be examined, the engineering design challenges followed the engineering design process steps. The design challenges also presented information on criteris and constraints related to the design.

Tasarım Görevimiz: Rüzgar Türbini Tasarlıyoruz!

Yaşadığınız bölge elektriğini kömürden enerji sağlayan enerji istasyonlarından elde ediyor. Yerel şirketler kömür kaynaklarının tükendiğini ve elektrik üretmek için farklı yollara ihtiyaç olduğunu belirttiler.



Maliyeti düşük rüzgar türbinlerinin elektrik enerjisi üretmede faydalı olabileceği görüşü ön planda. Siz uzman mühendislerden bugün yerel şirketlerin ricası üzerinde farklı fikirler ve çözüm önerileri bekliyoruz !
Takım halinde basit malzemeleri kullanarak bir rüzgar türbini tasarımı ortaya koyunuz !

Bu tasarım görevi için kullanabileceğiniz bütçe en fazla 40 tl dir. Toplam iki buçuk saat süreniz bulunmaktadır.

Figure 10. Visuals on the PD documents

3.6. Data Analysis

Data analysis resulted in a summary and synthesis of the findings. Data analysis strategies were explained separately for the qualitative data and quantitative data.

3.6.1. Analysis of the Qualitative Data

Qualitative data was collected with the written assessments, item paneling, cognitive interviews, teacher logs and clinical interviews. Figure 11 presented the overall data analysis strategies for qualitative data collected with; a) written assessments, b) cognitive interviews, and c) teacher logs and clinical interviews.

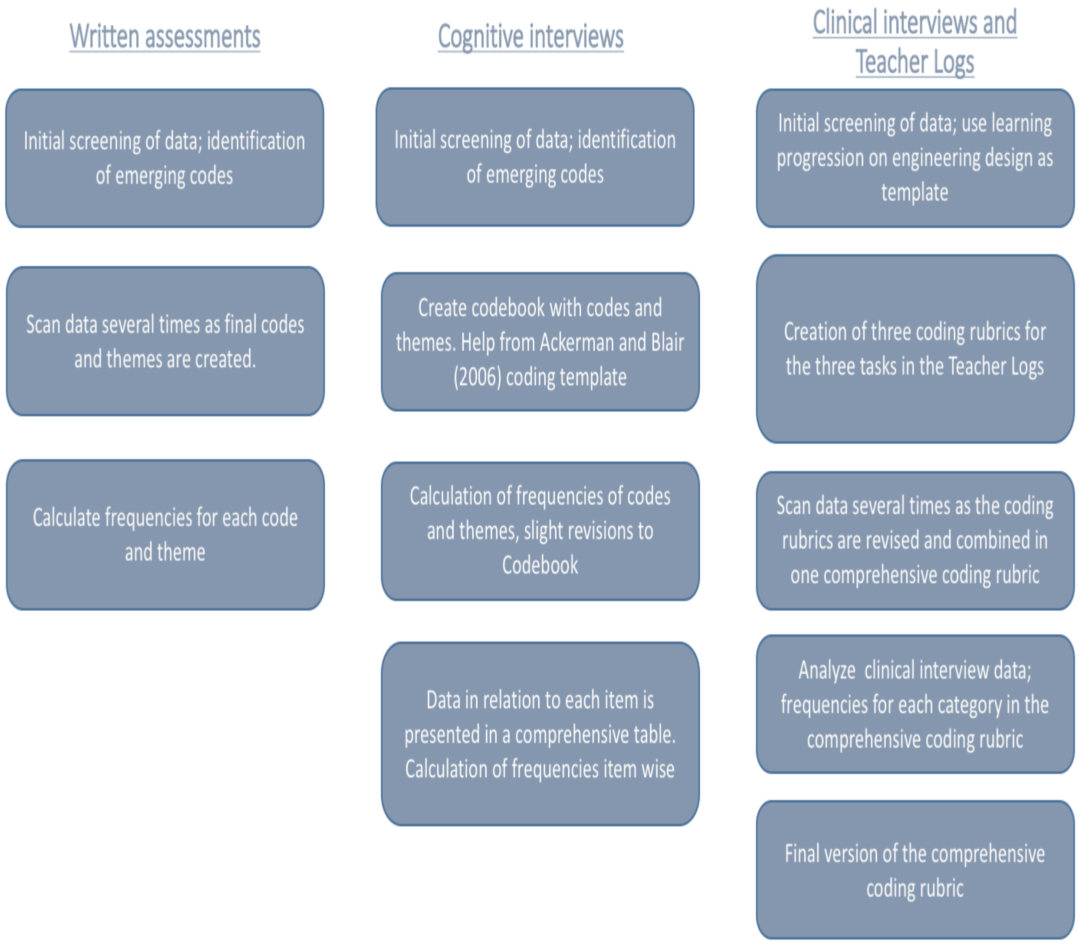


Figure 11. Data analysis strategies for qualitative data

Only the field notes taken were carefully examined for the analysis of data collected at item paneling. This resulted in summarization of the comments and recommendations found in the field notes. No further qualitative data analysis was conducted. For descriptive examination and summarization, the field notes were read to identify the most common recommendations by the panellists. Therefore, the careful reading of the notes aimed to summarize the notes under recommendations. The frequently mentioned recommendations by the panellists were taken into consideration on refinements of the learning progression levels, survey items, and administration procedures of the survey. The process described was carried out separately for the two item panelings.

For the written assessments, data was analysed in three phases (see Figure 11) which was inspired by the data analysis strategies by Miles and Huberman (1994). First, teachers' responses to the written assessment questions were carefully read with paying attention to emerging codes. These emerging codes were identified based on their repetition as teachers' responses were read several times. At this phase, no calculation of how many times these codes appeared in the responses was made. Later at second phase, the list of emerging codes was examined and the responses were read several more times paying attention to the list of emerging codes. During this phase first it was recognized that some of the codes in the list of emerging codes were more commonly found in teachers' responses. The least frequent codes were deleted from the list. Later in the third phase, the remaining codes were calculated on how many times they were repeated in teachers' responses. The codes with the highest frequencies were revealed which resulted in the final list of codes. As a last step, the codes were organized to be expressed under general themes. This resulted in minor revisions to the list of final codes, a few codes were deleted, or modified. The three phases explained for the data analysis of the written responses were completed separately for the written assessments on attitudes, and for the written assessments on engineering design process.

To continue, for the analysis of data collected through cognitive interviews, the first step was to examine the five data analysis strategies for cognitive interviews depicted in Figure 12 (Willis, 2015, p. 60). For the current study, a merge of Analysis Model 4; Theme Coding and Analysis Model 5; Pattern Coding was followed which were both illustrated in Figure 12. Then the data analysis was completed in four phases (see Figure 11) in light of the two data analysis models merged and followed. This necessitated the analysis of data with a bottom-up approach where codes and themes were built from the data; making use of patterns and associations (Willis, 2015).

In order to prepare the data for analysis, audio-recordings of the interviews were transcribed verbatim. Then at the first phase of data analysis, the transcripts were carefully read to identify emerging codes. As in the case of the data analysis of written responses, the emerging codes were identified based on their repetition in the transcripts. In the next phase, the codes with higher frequencies were determined with reading the transcripts a few times more. At this point, notes taken during the interviews were also helpful. Such notes were illustrated in Figure 12 as well under Raw Data as Interviewer Notes and quotes. In order to create a Codebook with the finalized codes; codes with the highest frequencies, the two general themes in a cognitive interview data analysis proposed by Ackermann and Blair (2006) were used. The two overall themes in the Codebook were: a) problems with how readily the question is understood (semantics) and b) problems with retrieving information or formulating a response (response task). The final codes were summarized under these two themes.

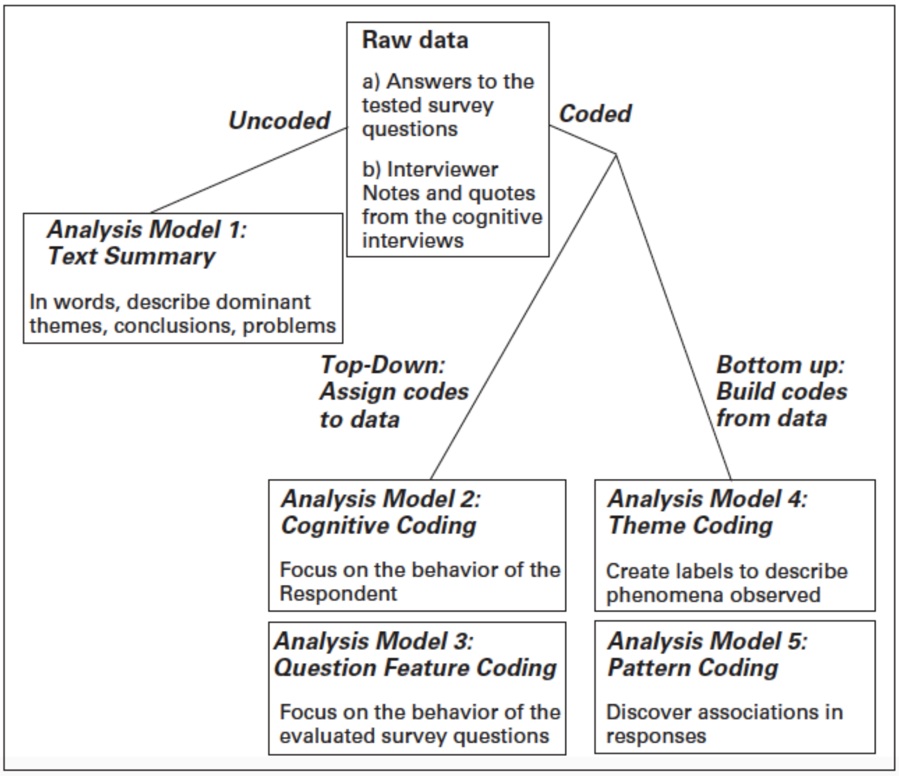


Figure 12. Data analysis models for cognitive interviews (Willis, 2015, p. 60)

In the next and third phase, the transcripts were scanned carefully to calculate frequencies for the codes. During this step, many revisions took place in the Codebook. To set an example, the code “VAR_YES” that explained having a wide range of responses from the participants; ranging from strongly disagree to strongly agree, was deleted from the Codebook due to lack of high frequencies. For an example of a change in a code, the code; SIT was combined with another code; CON. SIT_CON was used to describe situations and contexts where teachers talked about differences between the situation and context of schools types, and number of teachers working in a particular school. However, in second step, with more careful consideration, it was recognized that teachers gave many different examples of various situations and context. They did not particularly address schools type. Therefore, whenever teachers mentioned differences in situation and context, the more generic code; SIT_CON was found to be sufficient. While codes were inserted on the transcripts, some slight changes still occurred. These can be reported as removal of the codes on teachers’ agreeing or disagreeing with the item, and creating a new code that addresses changes and recommendations by teachers. Also due to very low frequency, three codes that were on item consistency, item repetition and use of examples were removed from the Codebook.

Following the exemplified removals and changes in some of the emerging codes a final Codebook was generated. Codebook in Table 20 included three parts. The first part included the label for the codes that were used as the researches coded the data. The second part presented a description for each code. These descriptions were helpful in the coding process of the data because at some points it might be confusing to decide which code should be used. The last column of the Codebook presented the items that had at least a frequency of one for that code. However as will be discussed later, not every item associated with a code went through a revision. This column only intended to reflect the overall items in relation to each code; not necessarily a revision in all items in this column was administered. As can be noticed, the generation of the Codebook was a recursive pattern, where after each step explained, removed and emerging codes were considered carefully. The final frequencies were calculated based on all transcripts as the codes in the final Codebook appeared.

A comprehensive analysis of the results necessitated an examination based on the items separately as well. In order to do this, in the fourth and the final step, a separate excel sheet was created for the items for phrases that belonged an item in particular. Later this excel sheet was converted into a comprehensive table to examine the frequency calculations item wise. This table was later merged with the Codebook as the column on the very right hand side. The item wise frequency calculations helped to understand which items had the lowest and highest frequency for each code. To summarize, the relation between the items and the codes were documented clearly. This was a major step to reach overall findings of the cognitive interviews and to make the necessary revisions on items. In this table, even the low frequency item-code relationships were put forth. However, for a revision to take place in the survey items, at least a frequency of five was seeked for. So in order to take the code for the particular item into consideration, codes with at the least a frequency of five were carefully identified.

For the analysis of data collected with the teacher logs and clinical interviews, several steps were followed to analyse the data. Data analysis began with the teacher logs. The unit of analysis was captured in teachers' accounts of engineering design process (e.g. accounts of teacher logs task 2). The identification of unit of analyses was useful in making comparisons between accounts of the same task either in the clinical interview, or the teacher logs, for teachers from different categories; novice, intermediate, and expert. To set an example, the teachers could respond to a question on engineering design process steps, by defining each step or by explaining steps as making comparisons in different models along with giving real world examples. Next, separate coding rubrics in line with each task on the teacher logs were created. An example coding rubric for two levels that was used to examine written assessment responses of students to refine a learning progression on energy was provided in

Figure 13 by Jin et al. (2013). In preparation of the coding rubrics for the current study, two example studies on learning progression development were especially helpful; Jin et al. (2013) and Mohan et al. (2009).

In total, there were three coding rubrics prepared to analyze the data reflecting the three tasks in the teacher logs. The systematic coding rubrics reflected the learning progression levels and helped with analyzing and coding responses of teachers. The coding rubrics included ordered levels of achievement in terms of understanding of engineering design for each task. First draft versions of these coding rubrics were generated each consisting of four ordered levels, from novice level understanding (lower level) to mastery level understanding (higher level or the upper anchor). Later, as the data was scanned multiple times, the levels were revised with addition or deletion of new statements within each level for each task. Each level in the coding rubrics were finalized according to the frequencies. These frequencies referred to number of teachers reporting the same code. These were calculated separately for responses of each group of teachers; novice, intermediate and expert. To set an example, the responses of teachers in the novice group for a particular task were analyzed together to inform the lower levels of the progression. Likewise, the responses of teachers in the expert group for a particular task were analyzed together to inform the higher levels of the progression. Following the revisions, final versions of the coding rubrics were generated. Each statement in the ordered level in the coding rubrics can be thought of as a code. As a last step, the three coding rubrics were evaluated together and consistent points for each level of the learning progression were combined. This resulted in one comprehensive coding rubric with three identified aspects of engineering design process.

Level	Specific level description	Exemplar responses from students
L4	(1) Identify light as the main (external) energy source for plants (without converting energy and matter). *AND* (2) distinguish between light and matter sources. *Do not need to*: Describe that light is transformed into chemical energy	Chose Light; Explanation: Light is where plants get the energy to produce food (glucose). Photosynthesis takes place when CO_2 is absorbed from the air and reacts with H_2O to produce glucose and O_2. O_2 is released into the environment through stomata
Distinction between L3 and L4: L4 students note light is the sole energy source for plants whereas L3 students additionally include other things as energy source for plants		
L3	(1) Describe that plants make their own energy by photosynthesis, or making glucose or food from water, light, air, and/or nutrients. May choose water, air, and/or nutrients as energy sources in addition to light. *Do not need to*: (1) Describe how light energy is transferred to chemical energy in glucose	Choose water, light, air, and plants make their own energy; Explanation: Water is an energy source for plants because it allows photosynthesis to take place. The same is true for light and air they allow photosynthesis. Nutrients in the soil, I feel do not aid in giving the plant energy. Through photosynthesis plants produce glucose, which serves as their source of energy

Figure 13. Example coding rubric (Jin et al., 2013, p. 1697)

For the clinical interviews, audio data coming from 10 teachers was transcribed verbatim. Different from analysis of teacher logs, separate group of teachers; novice, intermediate, and expert were not analyzed together as a group. The reason was that since the clinical interviews were conducted following the teacher PD program, there might have been changes in the categorization of the teachers. Although the sample was selected based on this categorization, all transcripts were analyzed together based on the comprehensive coding rubric created with the data analysis of the teacher logs. Accounts of teachers were coded according to the statements on the comprehensive rubric statements treated as codes. The code calculations were not done on number of codes emerging; frequencies, but on umber of teachers with each code. This resulted in a revised version of the comprehensive coding rubric. Finally, the final comprehensive rubric was examined in relation to the second version of the learning progression. With this examination, the third version of the learning progression on engineering design understanding was created.

For teacher logs and clinical interviews, to decide on the common codes, data coming from the majority of the teachers; that was data coming from at least five teachers was taken into consideration for each group of teachers; novice, intermediate, and expert. The rationale for this selection was that five and more teachers represented more than half of the participant group. The unit of analysis was the number of teachers, not the number of each code. This was due to the fact that the main goal was the identification of each level based on commonalities among the teachers. If a certain code or theme is frequently used by only two teachers, then this was not accepted as a commonality. In order for a certain phrase to be accepted to be put into levels, the main criteria were that it was frequently used by more than half of the teachers; addressing more than average; a majority.

3.6.2. Analysis of the Quantitative Data

Construct modeling (Wilson, 2005); a particular measurement framework guided the analysis of the quantitative data. Construct modeling is very useful for studies interested in developing a construct map together with its associated instrument (Wilson, 2005). Construct modeling helps to empirically align a construct map with its associated assessment (Wilson, 2005). For the current study, as discussed before, the learning progression developed on teacher attitudes can be referred to as a construct map because it is a simpler version of a learning progression. However, in order to maintain a consistent language throughout the study, *learning progression* was the common naming for both focuses. The associated survey for the learning progression on teachers' attitudes was a Likert-Type survey. Responses to the items in the survey corresponded to certain levels on the learning progression. The quality of the alignment between the levels and the items was revealed by following construct modeling. The construct modeling measurement framework was only followed for development of the learning progression on teachers' attitudes.

Construct modeling measurement framework includes four basic building blocks; a) construct, b) item responses, c) outcome space, and d) measurement model (Wilson, 2005, p. 15). This framework and its four bulding blocks were followed to analyze the data collected with the survey on teacher attitudes; “Science Teachers’ Attitudes towards K-12 Engineering Education Survey”.

With the first building block, *construct,* probable hypothetical levels are created. Each level reflects a hierarchical stage through which individuals pass (Briggs et al., 2006). In the second building block, *item responses,* items connected with the levels of the learning progression which would elicit the responses from the participants were formed. For the current study, a particular survey was developed; “Science Teachers’ Attitudes towards K-12 Engineering Education Survey”. For the second building block, the critical point is creation of items with scoring and response categories that align with the levels of the learning progression. The survey developed on teacher attitudes was a Likert-type survey with five response categories ranging from strongly disagree to strongly agree. Each response category of the items corresponded to a one particular level of the learning progression. To set an example, the response category; strongly agree corresponded to the highest level of the learning progression; advocate. Thus, survey development was the necessary step to complete the second building block. The third building block; *outcome space,* includes both the administration of the data collection tool, and preparing the data for analysis. First, the survey with its second version developed throughout the current study, was administered to 30 middle school science teachers during the teacher PD program at Phase 2 (see Table 4). Teachers’ responses were collected to the 22 Likert-type items. The responses were not scored by the researchers; teachers’ self-report responses were the scores obtained. Second, three input files were created, that are required to conduct the statistical analysis later in the R Studio program. Although the input files were created in Microsoft Excel, they were saved in CSV format which can be edited in text editing programs (e.g. Textedit, Notepad), and spreadsheet programs (e.g. Excel). The first file; *construct information (consInfo)*, presented information on both the number and names of the levels of the learning progression to R Studio. The category0 should always be left blank in this type of analysis. A screen shot can be observed in Figure 14.

Construct.ID	Long.Name	Short.Name	Cat0	Cat1	Cat2	Cat3	Cat4	Cat5
11111	Attitude	A	blank	resistant	doubtful	neutral	supporter	advocate

Figure 14. Construct information file

The second file; *item information (itemInfo)* presented information on the number and labels of the items. As can be examined in Figure 15, there were 22 items in total entered in this file. Another point presented was that the possible score that can be obtained for each item and response category was one. The fourth coloumn addressed the fact that the learning progression has five levels with the denotation; 11111. These levels of the learning progression lay between cat1 and cat 5. For the fifth coloumn labeled as cat0, the entire coloumn should be entered as 1 for this type of data analysis with R studio. The final and the third file; *scored responses (wide),* presented the scores of teachers to the items to R Studio. Each teacher was denoted by one row of an Excel file, where there were 22 coloumns representing each item.

Item.No	SG.ID	Item.Name	Construct.ID	Cat0	Cat1	Cat2	Cat3	Cat4	Cat5
1	1	q1	11111	1	1	1	1	1	1
2	2	q2	11111	1	1	1	1	1	1
3	3	q3	11111	1	1	1	1	1	1
4	4	q4	11111	1	1	1	1	1	1
5	5	q5	11111	1	1	1	1	1	1
6	6	q6	11111	1	1	1	1	1	1
7	7	q7	11111	1	1	1	1	1	1
8	8	q8	11111	1	1	1	1	1	1
9	9	q9	11111	1	1	1	1	1	1
10	10	q10	11111	1	1	1	1	1	1
11	11	q11	11111	1	1	1	1	1	1
12	12	q12	11111	1	1	1	1	1	1
13	13	q13	11111	1	1	1	1	1	1
14	14	q14	11111	1	1	1	1	1	1
15	15	q15	11111	1	1	1	1	1	1
16	16	q16	11111	1	1	1	1	1	1
17	17	q17	11111	1	1	1	1	1	1
18	18	q18	11111	1	1	1	1	1	1
19	19	q19	11111	1	1	1	1	1	1
20	20	q20	11111	1	1	1	1	1	1
21	21	q21	11111	1	1	1	1	1	1
22	22	q22	11111	1	1	1	1	1	1

Figure 15. Item information file

In the fourth and final building block, *measurement model*, a Rasch analysis was performed with the statistical data analysis program; R Studio. A Rasch model is "a mathematical model that describes the relationship between the probability of correctly answering an item and the difference between the person's ability and the item's difficulty" (Jackson et al., 2002, p. 234). The results of the data analysis can provide information on both the respondents and the items of the instruments. With Rasch analysis, the items' success in separating them to the levels of the learning progression can be identified (Fulmer, Liang, & Liu, 2014). The Partial Credit Model (PCM) was selected as the measurement model which is an extension of Rasch Model in the case of polytomous items (Baek & Kim, 2008). This was found appropriate particularly also due to the assumption that the distance between the response categories within the items may be different rather than being equal. Therefore, the estimation was that the steps may vary within items and also across items.

Right after the analysis was run, output files were prepared by the statistical program; R Studio in the same file where the three input files explained were put. These newly created files included numeric results on Excel files as well as visuals as tables and figures. With the files produced through the analysis run on the statistical program, findings on item fit-misfit, respondent-item distribution, items' capability of differentiating teachers, reliability estimates of both the items and the respondents were found out (Djaja, Youl, Aitken, & Janda, 2014; Lee & Liu, 2010; van Rijn et al., 2014). Following the construct modeling measurement framework helped to follow a systematic process to reveal information on the performance of the items, and on the empirical alignment between the learning progression and the survey; validity estimates.

3.7. Trustworthiness of the Study

Several measures were taken to ensure the trustworthiness of the study. According to Lincoln and Guba (1985), trustworthiness can be described with the following expression:

> "How can an inquirer persuade his/her audiences (including self) that the findings of an inquiry are worth paying attention to, worth taking account of? What arguments can be mounted, what criteria invoked, what questions asked, that would be persuasive on this issue?" (p. 290).

The codes were reviewed with discussions on disagreements as well as additional emerging themes. The data analysis continued until a consensus was reached on the codes and the themes. Following the discussions, codebooks were generated to code the interview results, which contributed to objectivity. Having multiple data sources thought the study contributed to the trustworthiness of the results. During the data analysis and in particular the coding processes of the qualitative data, other two raters helped for the inter-rater reliability. Both raters were PhD students at a public university. The first rater was registered to the program; Curriculum and Instruction and the second rater was registered to the program; Arhitecture and Design. They were selected based on their convenience and on their former experiences with qualitative data analysis. They were both not familiar with cognitive interviews and clinical interviews. So in cases where necessary, they were provided with necessary information.

For the calculations of the inter-rater reliability values, three steps were followed. These steps were followed separately for teacher logs, cognitive interviews, and clinical interviews. First, the researcher provided an overview of the goals of the data collection method to work on for the inter-rater reliability check. For example, for the inter-reliability calculation of cognitive interviews, the main goals of conducting a cognitive interview and its relevance to the current study were clarified. As a second step, one of the verbatim transcripts, or results of teacher logs of the participants was selected. This selection was based on inclusion of more number of codes. Later a copy of the same transcript or written responses along with the Codebook was provided to both raters. Right before starting to code, each code in the Codebook was explained to the rater. Any confusions were discussed at times when codes were not clear. At the next step, each rater separately coded three pages of their copy based on the Codebook. At times of disagreement, small discussions took place when the rater seemed to understand a code too differently. At such times, clairification was ensured by going over the explanation and examples of the codes. This was followed by another round of coding where both raters were clear on all codes. Following that, a chart was prepared where common codes, and separate codes coded by the raters were clearly noted. Out of 30 codes, a percentage was calculated by dividing the number of common codes to the number of total codes. This calculation revealed the value of the inter-rater reliability.

For the data analysis of teacher logs, the inter-coder reliability was around .77, for cognitive interviews, the value was .67, and lastly for the clinical interviews, the value was calculated to be .76. According to Krippendorff (2004) the inter-rater reliability values were acceptable. Only the value for the cognitive interviews was weak. This could be due to the fact that, the second rater had difficulty at points in understanding the flow of the interviews due to lack of experience on engineering design. Calculating inter-rater reliability with another rater might increase the value.

To have confirmation about the analysis results of the quantitative data, a PhD student and researcher in one of the public universities in USA who was experienced in R studio analysis conducted the statistical analysis the R Studio statistical program. The three input files to run the statistical analysis was sent to her. Therefore, she could conduct the analysis by using the same input files that the researcher used. It was found out that the results confirmed each other in terms of the output files created.

Triangulation of the data collected is critically important to ascertain the refinement of the final versions of the initial learning progressions (Cobb et al., 2003; Yıldırım & Şimşek, 2013). Having multiple data sources for the development of the initial learning progressions was important for the trustworthiness of the study. For an enhanced reliability and objectivity of the findings, triangulation of data sources is always critical for design-based research (Yıldırım & Şimşek, 2013). Triangulation can enable the revision and the final versions of the methodology framework and the instruments. The triangulation of data sources served to the validation of the learning progressions and the survey developed on teacher attitudes. Implementation of a teacher PD program was also important to test the learning progressions and enhance their validity.

Following the construct modeling measurement framework for developing the learning progression and survey on attitudes, information on reliability and validity was accessed. Both the reliability arguments and the validity arguments for the initial learning progressions and the associated survey were ensured with the several steps (Wilson, 2009). For reliability measures, internal consistency reliability coefficients; two Cronbach's Alpha values (Cohen, Manion, & Morrison, 2007) were identified; one for the item separation reliability, and one for the person separation reliability.

There were four sources of validity evidence for the learning progression and its associated survey on teacher attitudes. These can be listed as; a) evidence based on instrument content, b) evidence based on response processes, and c) evidence based on internal structure. (Wilson, 2005). For validity evidence based on instrument content, creation of items through a comprehensive literature search and consultation with experts in item paneling helped to improve the content validity of the instrument and the learning progression. For evidence based on response processes, analysis of data from potential responses of the survey and the learning progressions obtained with written assessments and cognitive interviews contributed to the validity. For evidence based on internal structure, statistical analysis was run which revealed critical information on item separation, item difficulties respondent separation and respondent abilities. These results helped to refine the learning progression and the survey which positively impacted their enhanced validity. As for the last point, to minimize instrument decay, data analysis procedures were clearly scheduled.

3.8. Role of the Researcher

I have a B.S. degree in science education, and experience on science teaching, implementation of engineering design challenges, design and delivery of professional development programs on STEM education and engineering design for both teachers and K-12 students. Having previous experience on engineering design was helpful for me to lead and contribute to the current study. I had the assumption closer to a qualitative and an interpretivist researcher in that I believed in the existence of multiple truths rather than an absolute truth. I was interested in thick descriptions of the participants and in gaining detailed information. In line with the main role of a researcher for the current study, I was not detached from the study nor from the participants; I was involved as part of the study. In especially the data collection procedures, I tried to be aware of my own view of the world and pre-assumptions so that I would not distort the results in any way. All data in the current study was collected by me. I tried to be sensitive about objectivity issue during the data collection and data analysis procedures (Yıldırım & Şimşek, 2013). I gave information to the participants about the goal of the study in general, and other necessary information for them to feel comfortable. Mutual trust was established between me and the participants during data collection. I used the experience I gained during the M.S. program I graduated from; Guidance and Psychological Counseling during the interviews; in establishing rapport, listening actively, and appreciating the participants.

3.9. Limitations of the Study

The limitations of the study were concerned with the nature of the learning progression development, the role of the researcher, data collection procedures, trustworthiness and sampling. With the written assessments, data was collected online. Although collecting data online has some disadvantages, it brings about some advantages such as reduced cost and being labor free of boundaries due to location (O'Neill, 2004). Another issue related to the written assessments was about the selection of participants. If the participant teachers were selected reflecting different levels of attitude and also engineering design understandings, then better results could have been achieved. Although the results of the written assessments contributed to the first versions of the learning progressions, still the first version of the learning progressions were impacted mostly by the literature findings.

One of the major limitations of the study was concerned with the nature of learning progression development. Typically developing, validating and presenting the final versions include many cycles of data collection, data analysis, and refinements. Due to timing and feasibility purposes, the current study completed one research cycle. With inclusion of more number of researchers and more amount of time, the number of such cycles of data collection, analysis and refinements can be extended. Again related to the same issue, the development of learning progressions commonly includes innovative data collection strategies such as clinical interviews and think alouds within them. With more experience on cognitive interviews and clinical interviews, data collection procedures could be more effective.

As another limitation, almost all data collection tools were developed and administered by the researcher. Actually, this was the inevitable nature of the study as the main goals were to develop new tools. Products went through many procedures to enhance their quality (e.g. small piloting, item paneling, cognitive interviews, clinical interviews, assignment of an additional rater) but still one could be suspicious about their reliability and validity.

One of the limitations was that for the cognitive interviews, it was conducted with 10 teachers which was quite a large sample. However, cognitive interviews often involve more than one round of interviews with again 10 respondents. So after the revisions to the survey developed with analysis of the cognitive interview data, one more round of interviews could be conducted with the revised survey, with another group of teachers. This could add more reliability and validity to the survey which could affect the development of its later version within the current study.

Two of the critical threats to the interval validity of the study was concerned with the implementation of the teacher PD program. This program included a unique setting to align it with the learning progression on teachers' engineering design understanding. Secondarily as a future goal, the program and the learning progressions together aim to raise teachers who are aware of engineering and who can integrate engineering to their instruction. At this point, the threats to the internal validity of the study were; implementation, data collector bias and instrument decay. Although the researcher collaborated with many professionals (e.g. engineering faculty members, engineers working in the field, educational sciences and science education faculty members, curriculum development experts) in both the design and delivery stages of the teacher PD program, still almost half of the activities in the program were administered by the researcher. The researcher was the same person who collected the data with survey on attitudes, teacher logs and clinical interviews. Unconsciously, at some points the researcher might have led the data in a way to reach the most useful data. As precautions, the researcher tried not to lead participants in any way and during interviews, and the researcher remained neutral not to guide the participants in any certain way again.

Related to data collection again, the amount of data to analyze throughout the study could create fatigue on the side of the researcher. Being tired might have unconsciously caused the researcher to score the data in different and inaccurate ways.

Another limitation was about the grain size of the developed learning progressions. The current study used a teacher PD program to: a) validate the learning progression on teacher understanding of engineering design, and b) to improve teachers to have knowledge and experience on engineering since in Turkish context most teachers are unfamiliar with engineering. This was useful to enhance the validity of the learning progression however it was recognized that most learning progression studies include curricular activities or development programs that covers a longer period of time. The PD program in the current study was only a two-day program.

For the data analysis of teacher logs and the clinical interviews, the researcher created coding rubrics which are typical for learning progression studies for the analysis of data. This process could be even more strengthened by creation of coding rubrics for each questions instead of doing it for each task. This could result in a more detailed analysis of data and to capture better distinguished levels. Considering the feasibility and timing issues, still creating the coding rubrics for each task revealed many distinguishing points between teachers of different ability levels which was critical for the goals of the study.

One limitation was about teachers' selection to the teacher PD program. Teachers were selected to the teacher PD program based on their experience and knowledge with engineering design to be able to validate the learning progression on engineering design understanding. However, this differentiation of teachers as novice, intermediate and expert only relied on their responses to two main questions on the application form which was a Google Form. Responses to questions to understand teachers' different levels of understanding of the engineering design was found to be successful when the same group of teachers' clinical interviews were categorized. However, the categorization of the teachers could rely on more sound evidence. Teachers could be asked more number of questions on the application form. To be more precise, more information could be collected from teachers as they applied to the program, so that better differentiation points between teachers could be revealed. This categorization was critical since it effected the results of the clinical interviews and teacher logs as well. However, the selection was successful at the same time in that it reflected different levels of understanding of the engineering design process, from novice to more sophisticated. The researcher experienced one of the disadvantages of purposive sampling that is it relies on the judgement of the researcher (Fraenkel et al., 2012).

Lastly, particular to the survey developed on teacher attitudes, a larger sample size could result in a more informative results on the well-functioning and not so well-functioning aspects of the survey.

CHAPTER 4

RESULTS

The results were presented in two major sections in line with the research questions of the study. The first major section answered the first research question and its sub-question of the study:

> 1. How can science teachers' attitudes towards K-12 engineering education be depicted with a learning progression?
>
> 1.a. How can a survey on science teachers' attitudes towards K-12 engineering education be developed to validate the learning progression?

In order to report the results of the study in answering the above questions, the three versions of the learning progression on teachers' attitudes and the survey; "Science Teachers' Attitudes towards K-12 Engineering Education Survey", were presented. The third and versions of these products were the final versions. Findings on how each version was developed and later refined were explained in the first section.

The second major section answered the second research question of the study:

> 2. What levels do science teachers typically experience as they move from a novice to a more sophisticated understanding of the engineering design process?

In answering the above research questions, three versions of the learning progression on teachers' engineering design understanding were presented. Findings on how each version of the learning progression was developed and refined with data analysis was described. The third version was the final version of the learning progression. The first major section reported the first, second and the third versions of the learning progression and the survey on teachers' attitudes respectively.

4.1. First Versions of the Teacher Learning Progression and Survey on Attitudes

For the development of the first version of the teacher learning progression on attitudes and the survey; "Science Teachers' Attitudes towards K-12 Engineering Education Survey", a) a literature search was conducted and data collection and b) analysis with written assessments were completed (see Table 4).

a. Literature search. This first research step involved using the existing literature sources to inform the levels of the learning progression (Alonzo & Steedle, 2009; Windschitl et al., 2012). The procedures followed to access the sources that can inform the learning progression and the survey development included three phases. These were: 1) Search; to retrieve the studies, 2) Selection; to apply inclusion criteria, and 3) Synthesis; to reach an overall summary of the included studies. These three phases were adapted from the systematic literature methodology of Borrego et al. (2015). The first two phases included retrieving useful studies through utilization of key search terms. The focus was on conducting searches in databases to access studies and on making eliminations through inclusion criteria. The third and the last phase involved a careful reading of the selected studies in order to reveal common patterns and to reach a summary to inform the learning progression levels.

For the first phase, a search was conducted in the following databases; Ebscohost, Google Scholar, and Web of Science. The key search terms that provided the most relevant articles were "K-12 engineering education" in combination with "attitudes"; similarly, "STEM" in combination with "attitudes". Some of the key search terms also used were "teacher attitudes", "attitudes" in combination with "learning progressions", "attitudes" in combination with "construct maps", "K-12 engineering survey", and "STEM survey". The search was limited with studies published during a 16-year period from 2000 to 2016. The reason for this time limitation was that the literature was found to include more material on attitudes towards engineering and STEM and K-12 engineering education after 2000. The search included both articles published in peer-reviewed journals and conference proceedings to increase the number of useful results. As these databases were carefully examined to access studies, this phase resulted in 144 studies following the removal of duplicates, studies that did not share useful information in terms of sufficient details and studies that could not be reached as full-text.

Next an initial screening of the selected 144 studies was completed. Some were eliminated due to having focuses irrelevant to the goals of the search. Some of these irrelevant focuses were STEM cell studies, variables such as academic achievement, conceptions, and learning, and particular groups such as females and minorities. Lastly for the studies that used the same instrument to collect data, only one of them was put into consideration. With these eliminations, the number of studies decreased to 76. Following this, two inclusion criteria were applied to result in the most useful studies for the goals of developing the learning progression and the survey. These inclusion criteria were: 1) to have attitudes towards STEM and/or engineering as a focus, 2) to include administration of an instrument on attitudes towards STEM and/or engineering, or to present a work on developing a construct map or a learning progression on attitudes. The administration of these two inclusion criteria resulted in 21 studies in total. Details on the final tally of these 21 studies were presented in Table 12.

The table included four groups that helped examine the studies. These were; students' and teachers' attitudes towards STEM and/or engineering (n = 21), b) administration of a survey on attitudes (n = 19), c) categorization of levels on attitudes (n = 4), and d) main contribution of the study (n = 21). Studies in the first group; students' and teachers' attitudes towards STEM and/or engineering had an informative role on

Table 12. *Informative Literature on Teacher Attitudes*

		Attitudes towards STEM and/or engineering		Main contribution on			
Author	Year	Teacher Attitude	Student attitudes	A survey on attitudes	Levels on attitudes	Learning progression levels	Item
Sun	2013	x				x	
Chao	2014		x	x			x
Nguyen	2012	x		x	x	x	
Nuansri	2016		x	x	x	x	
Mahat	2008	x		x	x	x	x
Al Salami	2015	x		x		x	
Lachapelle	2014	x		x		x	x
Yaşar	2006	x		x		x	x
Buyruk	2014		x	x			x
Yu	2012	x		x		x	x
Faber	2013		x	x		x	
Yamak	2014		x	x		x	x
Lee	2006	x		x		x	x
Nugent	2010		x	x		x	x
Nadelson	2013	x		x			x
Berlin	2012	x		x		x	x
Wang	2015	x		x			x
Binns	2016		x	x			x
Tseng	2013		x	x		x	x
Teo	2010	x			x	x	
Unfried	2015		x	x		x	x

understanding points that signify having positive attitudes. All studies were marked to be in this group. The fourth and the last group concentrated on the main contribution of the examined studies for the current study. Although the above explanations were helpful on their guiding roles, still this fourth group made the process more systematic in terms of understanding how these studies impacted the current study. It should be stated that all 21 studies gave some ideas on both the levels of the learning progression and the items of the developed survey; "Science Teachers' Attitudes towards K-12 Engineering Education Survey". However, with a close examination it was recognized that some of the studies were especially helpful in both creation of the levels and the items of the survey at the same time (n = 11). For five of the studies (e.g. Nguyen & Griffin, 2012; Nuansri, Tangdhanakanond, & Pasiphol 2016), they particularly influenced the creation of the learning progression, whereas the remaining five studies (Binns, Polly, Conrad, & Algozzine, 2016; Wang & Nam, 2015) were mostly helpful in how to write items for the survey. In order to identify the levels of the learning progression; from *highly negative attitude* to *highly positive attitude*, studies marked on main "contribution on learning progression levels" were especially effective. These sources had major role in trying to understand the possible differences between teachers who have different levels of attitude towards K-12 engineering education, from negative to positive.

To give more detail, the diffusion of innovation model (Rogers, 2003) and the skill acquisition model (Dreyfus, 2004) addressed by one of the studies in this group; Sun and Strobel (2013) provided suggestions on how to organize and order the levels. One of the key points figured out with these models were the importance of learning and reaching information by the individual. Especially the lower levels gave ideas on the creation of the levels. Accordingly, in the lower levels where the change in attitude is observed, the teacher first acquires knowledge on the topic, does something to become involved in it, and then explores its value orientation. Later, uncertainty about the demands of the innovation, personal ability to implement it, and personal costs of getting involved, time demands and worries about organization, preparation and scheduling may occur. To summarize, both models described by Sun and Strobel (2013) guided what to include on the levels of the learning progression.

The second group presented leading information on the surveys used to collect data on attitudes towards STEM and/or engineering. Except for two studies; Teo and Waugh (2010) and Sun and Strobel (2013), all the remaining studies were in this group. The third part was composed of studies that showed a demonstration of how to categorize attitudes. The four studies in this group set influential examples of how attitudes can be put into increasing and decreasing levels on a continuum. Three of the studies in this group; Mahat (2008), Nguyen and Griffin (2003), and Nuansri et al. (2016) developed a learning progression in their studies along with a survey. So the procedures followed by these studies was similar to the current study. These three studies had a critically significant influence on how to place attitudes along a continuum. Some of the leading findings were on how to write items that can be empirically aligned with the levels of the learning progression. All developed their survey as a Likert-type survey for the ease of collection of data from larger samples and again the ease of matching the response categories with the levels of the learning progression. So the response categories of the Likert-type survey items in these studies, mostly ranged between strongly disagree to strongly agree. These response categories were aligned with the levels of the learning progression from the lowest level; highly negative attitude to the highest level; highly positive attitude respectively.

Mahat (2008) and Nguyen and Griffin (2003) both developed a learning progression on teacher attitudes along with its associated instrument. Both associated instruments were Likert-type surveys that helped validate the order of the learning progression levels. So both of these studies had a similar goal in terms of creating a learning progression and along with a survey to have an empirical alignment between the levels of the learning progression and the survey, and to validate both products. In that sense, these two studies were highly useful for the process followed in the current study as also explained in Chapter 2; Review of the Literature. A noteworthy point was that both studies labeled their learning progression as construct maps. This had two reasons: a) following the construct modeling measurement framework in analysis of data, and b) developing a one-dimensional learning progression. For the purpose of using a similar language for all products of the current study, *learning progression* label was used instead of a *construct map*. A construct map typically represents a one-dimensional latent variable. Many constructs are more complex than this; they may be multidimensional. This is not a barrier to the developing construct maps. Employing a construct modeling approach to developing instruments is helpful in supporting the instrument theoretically and empirically with the construct map levels (Wilson, 2005). The construct map is thought of less complex form of a learning progressions which is designed to conceptualize how assessments can be developed that have a theoretical base (Wilson, 2009). As to develop an instrument associated with the learning progression on teacher attitudes, following the construct modeling measurement framework was considered very suitable for the current study as well.

With the examination of the surveys that the studies used to collect data on attitudes, commonalities were put forth. These commonalities were detected to be in line with the commonalities that were explained above in terms of the points signifying changes in attitudes. To provide particular examples, the survey developed and implemented by Nugent et al. (2010) had two subscales; motivation and use of strategies. The first sub-scale; motivation concentrated on perceived value which measured participants' evaluation of importance, usefulness and interest. To continue, Teacher Attitude Survey (TAS) by Lachapelle et al. (2014) consisted of six sub-scales; relevance of engineering, pedagogy for teaching engineering, enjoyment of STEM subjects, when to teach engineering, characteristics of engineers, and improving abilities to teach engineering. This survey also addressed the motivation of teachers' in improving their understanding of engineering and in how engineering projects can be implemented in class. Especially the three subscales; improving abilities to teach engineering, relevance of engineering and enjoyment of STEM subjects were effective in guiding the creation of the learning progression levels and the items in the survey. Another survey developed by Yaşar et al. (2006); The DET (design, engineering and technology) survey was another source helpful in providing ideas on both the levels and item development. The DET survey is used for collecting data on teachers' perceptions of engineers and familiarity with teaching design, engineering, and technology. Its sub-scales to measure teacher attitudes were as follows; importance of DET, familiarity with DET, stereotypical characteristics of engineers, and characteristics of engineers and engineering. The first two sub-scales listed were useful in offering perspectives in the development of the survey. Another influential instrument was “A Conceptual Teacher Competency Model for Teaching Engineering” developed by Yu et al. (2012). The two dimensions of this model highlighted teachers’ attitudes towards teaching engineering and attitudes towards engineering. Some critical points useful for the purposes of the current study were willingness to design and implement, to improve knowledge and to learn concepts and ideas in engineering, understanding of impacts on society, attitudes toward teaching engineering.

Careful examination of the 21 studies helped with both identification of the levels of the learning progression, and construction of items for the survey; “Science Teachers’ Attitudes towards K-12 Engineering Education Survey”. The commonalities identified in level categorizations of attitudes and the surveys used in data collection on attitudes resulted in a theoretical basis for both the learning progression and the items in the survey. The common points reached with the literature search in addressing attitudes were; attaching importance and usefulness to engineering (Berlin & White, 2012; Nugent et al., 2010), having interest in learning and improving oneself (Binns et al., 2016; Hsu et al., 2010; Nugent et al., 2010), motivation towards preparing and implementing engineering practices in class, and enjoyment in teaching engineering (Faber et al., 2013; Nadelson et al., 2013).

The common points in these studies revealed that having interest in learning an improving oneself, having motivation to teach, giving value and importance, enjoyment, having awareness usability, and outcomes addressed having a positive attitude towards engineering education. These common points were candidates; a) to include in the levels of the learning progression from lower levels to higher levels, and b) to write items about. The final decisions on what to include in the learning progression levels and the survey items were given following the examination of results of the written assessments.

b. Written Assessments. Written assessments were conducted with two goals. These were to better inform; a) the levels of the learning progressions, and b) the items of the "Science Teachers' Attitudes towards K-12 Engineering Education Survey". The written assessments to inform the learning progression and the survey on attitudes were conducted with 14 in-service middle school science teachers in total all working in Turkey. The participants filled in the written assessment questions online. An example response by one of the participants was provided in Figure 16.

What do you think on the integration of engineering concepts and practices to science education?

I agree but there might be limitations. We use engineering practices in science lessons. Our students' creative skills and hand craft skills are very weak. With engineering in science, we can not expect the same growth and performance from each student however students will all learn fast with interaction of the disciplines. Their knowledge will be permanent, they will be more creative and successful.

Figure 16. Example response of Word document

In the first step of data analysis, the written assessments were scanned to detect some emerging codes. All emerging codes identified as the written assessment forms were examined carefully can be reviewed in Table 13.

Table 13. *List of Emerging Codes for Attitudes*

Emergent codes
Improve as a teacher
Keep pace with new demands of students
Professional development programs and seminars for teachers
Improves students' skills
Achievement / better learning-instruction in math or science
Interest / positive attitude in STEM disciplines and careers
Curriculum load/time and materials as limitations
Support of school management
Out of school projects
School materials not sufficient to meet needs of students
Improve student creativity
Increases student interest in science, engineering and technology
Communication
Creativity / creative thinking
Critical thinking
Problem solving
21st century skills
Hand-craft skills
Increase in student understanding
Contribution to society
Understand the work of engineers
Draw attention to integration of disciplines
Effective use of technology

As can be examined in the Table 14, teachers expressed their overall attitude towards K-12 engineering education focusing mostly on interest in learning and in professional development (*f* = 30), consideration of school context (*f* = 32), attaching value to student development (*f* = 61), and attaching value to improvement of society (*f* = 42). These themes were explained in more detail separately.

Table 14. *Results for the Written Assessments for Teacher Attitudes*

Themes and codes	Frequency (#)	Summary of findings
1. Interest in learning and in professional development	30	Teachers have an interest in learning about K-12 engineering education mainly through professional development opportunities. They are motivated to equip themselves with necessary knowledge and skills and to search for personal improvement opportunities.
Being equipped	16	
Opportunities to improve	14	
2. Consideration of school context	32	Teachers consider their school context in terms of the time and materials they will need to prepare for a lesson/activity on engineering. Teachers' attitudes might be effected by the level of preparation they might need.
Time	10	
Materials	10	
Good preparation	12	
3. Attaching value to student development	53	Teachers attach value to engineering education because they think it has positive effects on student development.
Interest in STEM disciplines	10	
Understand integration of disciplines	11	
Develop skills	32	
Creative thinking	13	
Critical thinking	7	
Problem solving	6	
Innovation	6	
4. Attaching value to improvement of society	33	Teachers attach value to engineering education because they think it has positive effects on improvement of the society.
Global issues, real-world problems	13	
Application of knowledge	8	
Products for the society	12	

Theme 1: Interest in learning and in professional development. The results revealed that teachers were interested in improving themselves professionally and in learning about K-12 engineering education. Thus, they were revealed to have a positive attitude towards improving professionally. In total majority of teachers (n = 11) reported that they felt motivated towards improving themselves. Teachers were revealed to be motivated to gain experience and improve themselves on K-12 engineering education as a teacher. They were interested in being equipped with necessary knowledge and skills to integrate engineering to their instruction (f = 16), and making use of opportunities to improve themselves as a teacher (f = 14). For being equipped with necessary knowledge and skills, teachers reported that they felt

the need to be sufficient enough for their students on K-12 engineering and related pedagogies. One of the teachers reported:

> *"As the Maker movement and STEM education is becoming more common, I should improve myself so that I keep pace with time and ready for my students."*

Teachers were motivated towards being equipped with necessary knowledge so that they can keep pace with the new pedagogies. To continue, for the second code, teachers were found to have a positive attitude towards making use of opportunities to improve themselves professionally. These opportunities included participating to seminars, workshops and other related trainings. One of the teachers stated the following:

> *"We as teachers should participate in continuous seminars, conferences and other sharing opportunities so that we improve ourselves….."*

For following such opportunities, there was an essential commonality for almost all teachers. Majority (n = 10) expressed that, they find it hard to learn about professional development programs they can participate in. One of the teachers reported:

> *"We can only hear about such professional development programs on Facebook science teachersgroups or from our friends. It is a bit challenging to learn about them.*

To summarize, for this theme, teachers were mostly positive about learning and improving themselves professionally on K-12 engineering education. This theme overall was considered to include points that reflected positive attitudes. This meant that improving oneself professionally on K-12 engineering education can be put in a continuum where highest level is interpreted as the highest degree of positive attitude.

Theme 2: Consideration of school context. In clarification of the theme; school context stood for teachers' differing attitudes depending on three factors that belonged to their school context as they implement engineering activities; time, materials and level of preparation. Overall this second theme revealed the points that can possibly make and reveal differences in teachers' attitudes. These most commonly expressed points were teachers' expectation/concern of the need for more time to prepare for engineering activities (f = 10), teachers' expectation of the need for appropriate materials to implement engineering activities (f = 10), and engineering activities requiring a good preparation by the teachers (f = 12).

For the first code; time was found to be a very critical consideration point for teachers. In total, 10 of the teachers expressed that time will be a limitation for them to integrate engineering to their instruction. One of the teachers expressed her opinion as follows:

> "*We as teachers might have difficulty in preparing the engineering activities. For us, we need to spend much effort and time for a quality activity.*

Most of the teachers (n = 9) seemed to worry about creating suitable time on their schedule to implement engineering practices. For the second code for this theme; access to appropriate materials, teachers' overall attitude was found to be in relation to ease of accessing the materials to implement an engineering activity. One of the teachers reported:

> "*......the economic issues in our schools will provide us from purchasing the materials and prepare them, at this point, teachers' own endeavor is what matters...*"

About this code; time, it was interpreted that teachers might differ in their attitudes in how they consider time. Thus, teachers' attitudes could change with the degree of time they are motivated to spend on engineering activities. To clarify, a teacher who has a highly positive attitude towards engineering education would be motivated to spend more time on engineering activities compared to a teacher with negative attitude. A similar interpretation was made for the second code, materials. Teachers seemed to imagine access to materials as a consideration point in applying engineering activities in their classrooms. Therefore, teachers with a positive attitude can be motivated to prepare their engineering activities with more variety of materials compare to a teacher who has less positive attitude. Motivation to expose student to more variety of different materials can be considered a sign of higher positive attitude. A teacher with less positive attitude can try to implement an activity with a very few materials only.

The third and final code for the second theme; referred to the fact that, teachers' attitude might depend on the effort they are willing spend in preparation and implementation of engineering activities. Teachers seemed to be reluctant and suspicious about getting prepared and spending much effort to successfully implement engineering activities. One of the teachers expressed his suspicion by stating the following:

> "*......the engineering design activities we will implement will require great effort in planning, design and implementing…"*

Another teacher's comment summarized some main points for this theme:

> "*......materials, planning, the loaded curriculum and the attitude of the school administration are all critical…we can have problems while we practice engineering activities.*

Teachers were found to think about the need for more effort in preparation to implement an engineering activity effectively in their classrooms. This third code was very similar to the interpretations reached with the first code; time. Again teachers' attitude reflects their motivation on how much effort teaches are willing to spend. To make it clear, teachers with a highly positive attitude were interpreted to be willing to spend more effort in preparing for in-class engineering activities.

To sum up, this theme discussed three points teachers felt unsure and might differ on their attitudes from negative to positive. Results under this theme was very helpful in imagining a continuum from negative attitude towards positive attitudes in that, possible reasons for teachers to have negative attitudes towards K-12 engineering educations were revealed.

Theme 3: Attaching value to student development. The role of K-12 engineering education for the development of students were among the major points highlighted in written assessments. In relation to the possible positive impacts of K-12 engineering education for students, there were common points for the majority of the teachers. This theme expressed teachers' positive attitudes mostly due to the future effects of K-12 engineering education for the students. Teachers claimed that K-12 engineering education can contribute to students' interest in STEM disciplines and careers (f = 10), understanding of the integration of disciplines (n = 11), and developing skills (n = 32) which included creative thinking (f = 13), critical thinking (f = 7), problem solving (f = 6), and innovation (f = 6).

Teacher were found to believe that students' realizing how people from different discipline collaborate and work on a problem is can be a contribution of K-12 engineering education. One of the teachers pointed out the following:

> "*......as the students solve engineering problems, they can realize how math and science disciplines are involved, this can result in their interest in these fields, of course at this point, teachers' guidance is critical*

Teachers were found to agree on the contribution of engineering education to students' understanding or recognizing of the integration of disciplines. A great portion of the teachers (n = 10) referred to this point as they discussed the possible contributions of K-12 engineering education in their responses. So according to the teachers, implementing engineering activities might result in students become aware how experts in multiple disciplines collaborate to work on problems. As for the third and final code for this theme; developing skills, teachers mostly responded to the written assessment questions referring to mostly three skills that students can develop as they are exposed to K-12 engineering education. One of the teachers responded as the following:

"As students design, they will use their brains more actively. Our students will look at situations from different perspective and they will improve in their problem solving skills"

The other two skills that teachers thought students can improve with engineering were critical thinking and innovation.

The results presented under this theme were helpful in understanding the place of contributions of engineering for students. This theme necessitated providing the results as signs of teachers' positive attitudes. To set an example, it was interpreted that teachers with positive attitudes can be the ones who agree to the role of K-12 engineering education on students' development. The skills addressed by the teachers were mostly used for developing items for the "Science Teachers' Attitudes towards K-12 Engineering Education Survey". The skills discussed with this theme were not directly addresses in the first version of the learning progression. This was explained in more detail in the following sections.

Theme 4: Attaching value to improvement of the society. The role of K-12 engineering education for the improvement of the society was another major point mentioned in the written assessments. This theme in particular included three codes; contribution of K-12 engineering education in solving global issue and real-world problems (f = 13), application of knowledge (f = 8) and creating products for the society (f = 12).

While 11 of the teachers mentioned the future role of engineering in classrooms in solving global issue and real-world problems, the rest of the teachers (n = 3) did not refer to this point. It was interpreted that these 11 teachers believed engineering education bringing solutions to global issues was a motivation source for them. Technological advancement was an example for the real-world problems:

> "*with the engineering activities, our society can improve, we are behind other countries in technological advances, engineering education can benefit us in this"*

Majority of the teachers presented their ideas in the written assessments forms highlighting knowledge can be applied with engineering activities (n = 8). This recurring code referred to the fact that teachers' attitude towards K-12 engineering education was positive due to the opportunity it brings in applying knowledge. As for the final code for this theme; creating products for the society, teachers seemed to have positive attitudes towards K-12 engineering education because according to them, it might generate useful products for the society.

For the four themes; the results of the written assessments, commonalities in teachers' responses were described based on the frequencies. These results were helpful in creation of the first version of the learning progression and the "Science Teachers' Attitudes towards K-12 Engineering Education Survey". The details on this process was elaborated on in the following section.

The results of the written assessments together with the literature findings, were influential in creating the learning progression and in writing items for the "Science Teachers' Attitudes towards K-12 Engineering Education Survey". Some findings were parallel in both the literature and the written assessment results. These were directly mentioned in the learning progression and the survey. However, there were conflicting points between the literature and the results of the written assessments at some points. All of these were explained separately. Points that reflected teachers' attitudes and points that teachers could possibly differentiate in terms of their overall attitude towards K-12 engineering education were identified. To summarize, the first version of the learning progression and the survey were both based on; a) literature search, b) analysis of written assessments, and c) a logical consideration of a possible proximity to the lowest and the highest level (Alonzo & Steedle, 2009). The first version of the learning progression guided by the above findings can be observed in Table 15.

To begin with the levels of the learning progression, the points that were highlighted for teachers' attitudes in both the literature findings significantly and results of the written assessments were summarized as: a) motivation to improve oneself professionally and to learn more (e.g. Lachapelle et al., 2014; Yaşar et al., 2006), b) attaching value to the role of K-12 engineering education in students' improvement (e.g. Bybee, 2010; NGSS Lead States, 2013; NRC, 2012), and students' interest (e.g. Jeffers et al. 2004), and c) attaching value to the role of K-12 engineering education in the improvement of the society (e.g. Lachapelle et al., 2014). Motivation to implement engineering activities or teaching engineering were also reflected; to what extent teachers are willing to prepare and teach engineering activities since these points were found to be addressed in the literature search. Lastly consideration of the school context, and teachers' the degree of the effort and time they are willing to spend. As can be noticed these points were place in the learning progression in all levels. However, the degree of attitude changed from the lowest level; highest negative attitude to the highest level; highest positive attitude. The points about teacher attitudes were placed in every level of the learning progression, but with a different degree; ranging from highly negative attitude to highly positive attitude.

Table 15. *First Version of the Learning Progression on Atttitudes*

Increase in positive attitudes
Advocate
Highly interested in learning about K-12 engineering education and engineering and design education. Highly motivated to improve oneself professionally through in-service trainings. Highly interested in implementing engineering design activities in classroom. Interested in implementing with good preparation; good effort and time. Likely to strongly agree that engineering and design education helps students to develop and the society to improve.
Supporter
Moderately interested in learning about K-12 engineering education and engineering and design education. Moderately motivated to improve oneself through in-service trainings. Moderately interested in implementing engineering design activities in classroom. Interested in implementing with some preparation; moderate effort and time. Likely to agree that engineering and design education helps students develop and that it helps the society improve
Neutral
Undecided about improving oneself on engineering and design education Undecided about engineering and design education helping students develop and helping society to improve
Doubtful
Little interest in learning and motivation to improve on K-12 engineering education and engineering and design education. Little motivation to implement engineering design activities in classroom. Only interested in implementing with minimum effort and time and/or when one is required. Likely to disagree that engineering and design education helps students develop and that it helps the society improve
Resistant
Avoids learning about K-12 engineering education and engineering and design education and improving oneself through in-service trainings. Avoids implementing engineering design engineering design activities in classroom Likely to strongly disagree that engineering and design education helps students develop and that it helps the society improve
Increase in negative attitudes

Throughout the learning progression levels, the connotation; engineering and design education was used. This aimed to bring more clarity, because the direct Turkish translation of K-12 engineering education might not be clear.

The common points revealed by reflecting on the results of the literature search and the written assessments were spread to the levels of the learning progression that would be in line with the response options of the survey developed; “Science Teachers’ Attitudes towards K-12 Engineering Education Survey”. Moving from these points addressed in both the literature and the written assessments, for the first point; motivation to improve oneself, this was interpreted as positive attitudes to learn about K-12 engineering education, improve oneself professionally and also included motivation to teach and implement engineering activities in classroom. For the second and third point development of students and the improvement of the society, they were again spread to levels of the learning progression with an increasing level of positive attitude.

With the next point, consideration of the school context, teachers expressed their reluctance and their suspicions when it comes to the time and preparation. Teachers seemed to be distracted in their positive attitudes when they thought about the time and preparation effort they might spend for implementing engineering activities in their classrooms. This was thought as a way to distinguish teachers with negative attitudes and teachers with positive attitudes. Also in terms of a logical consideration, it was presumed that someone with a positive attitude towards something will be the one who would like to spend more time and effort on it. This point was not given a particular focus on the learning progression levels, but reflected in the items of the survey.

The levels of the learning progression from the highest positive attitude to the highest negative attitude were labeled as; advocate, supporter, neutral, doubtful and resistant respectively. This first version was subject to change following results of the item paneling and cognitive interviews.

Table 16. *Outcome Space*

Response Choice	Score	Level on the learning progression
Strongly agree	5	Advocate of K-12 engineering education
Agree	4	Supporter of K-12 engineering education
Undecided	3	Neutral about K-12 engineering education
Disagree	2	Doubtful about K-12 engineering education
Strongly disagree	1	Resistant to K-12 engineering education

The survey associated with this learning progression was planned to be a Likert type survey. So the levels of the learning progression were designed to reflect this with its five levels. Table 16 presented the alignment between the five levels of the learning progression and five response categories for each item in the Likert-type survey. This presentation is labeled as outcome space according to the construct modeling measurement framework (Wilson, 2005). The items in the survey were developed particularly associated with the levels of the learning progression. Each response category for the items corresponded to one level of the learning progression.

The outcome space provides information on; a) the relationship of the survey items to the learning progression levels, and b) how to score the items and get ready for the statistical data analysis (Wilson, 2005). This was more closely elaborated on in results of the quantitative data analysis. In light of the findings of the data collection, the items were created as Likert type items. And as a design requirement, the instrument was planned to be easily administrable to large number of teachers in future. Hence, an appropriate fixed response format was selected as Likert type. All items had five response categories from strongly disagree to strongly agree.

To continue with the construction of the items of the survey, firstly the survey was labeled as "Science Teachers' Attitudes towards K-12 Engineering Education Survey". For the findings coming from the literature and the written assessments, an item pool was generated. A total of 56 items were written. Later, adhering to the first version of the learning progression created more carefully, many of the items were eliminated. Also to preventing teachers from getting too exhausted as they fill in the survey, revisions took place and the number of items were decreased to 25. The first version of the survey following mainly the learning progression levels that reflected the results of the literature search and the written assessments can be found in Table 17.

For the items in the survey, the learning progression created was the main source, which was a reflection of the results of the informative literature search and the written assessments. For each point highlighted in the learning progression levels, that only differed between the levels based on degree of attitude from low to high, items were created and finalized.

When the points addressed in the learning progression levels are considered separately, for motivation to improve oneself, learn and to teach, specific items were written on teachers' participation to seminars and professional development programs, learning and gaining experience on K-12 engineering education. In total, 12 items reflected this comprehensive point. For the second and third points in the learning progression levels, role of K-12 engineering education in the improvement of the society and development of students, detail was reflected in the items. For the next point consideration of school context in terms of time and effort, teachers' willingness to implement engineering activities was reflected. These items were *harder to agree* ones for the teachers. The number of the items for this point was lower dues its scope being narrower compared to the first point. Also this point was addressed mainly in the written assessments not in the informative literature necessarily.

Table 17. *First Version of the Items*

1.I would like to participate to a teacher training for two days on a weekend on engineering design practices.
2.With the integration of engineering design practices to the curriculum, students' interest in scienc mathematics, technology, and engineering will increase.
3.I would like to read sources that exemplify engineering design practices.
4.It makes me excited to gain experience on engineering and design education.
5.I believe engineering design practices will develop students' collaborative working skills.
6.I will be motivated to participate to a teacher training on 'engineering and design education'.
7.I enjoy investigating example in-class engineering design practices.
8. I believe engineering design practices will develop students' communication working skills.
9.Application of engineering activities in schools can contribute to solving problems societies face (e.g. environmental problems, economical problems).
10. I feel pretty much motivated to teach engineering design process to my students.
11.I am interested in searching for workshops for teachers on engineering and design education.
12. I would use my time and effort to conduct research.
13.I think that engineering education is important for application of knowledge.
14.If my school administration asks me to implement an engineering activity, I would accept it.
15. I would consider engineering activities to implement in my class with spending time and effort in researching on its preparation.
16.I am interested in participating to a teacher workshop on 'engineering and design education' only if I am required.
17. Engineering practices in K-12 classrooms is significant for the improvement of the society.
18. Engineering and design education helps students understand the collaboration of disciplines.
19. I am interested in implementing engineering activities if it is integrated to the curriculum.
20. If my school administration asks me to implement an engineering design activity, I will ask another teacher to do it.
21. Students' innovation skills can develop with the integration of engineering to curriculum.
22. I am motivated to have a student club after school where we implement engineering activities.
23. I think engineering education can improve students' critical thinking skills
24. It is critical for students to have a comprehension of engineering.

In preparation of the items, the Theory of Planned Behaviour (Ajzen, 1991) as used in Mahat (2008) in development of an instrument on teacher attitudes was also inspirational. Accordingly, some of the items inquired about affective dimensions of attitudes, some of the items addressed the cognitive dimensions of attitudes and the remaining items inquired about behavioral intent. The affective dimension was related to feelings and emotions, the cognitive dimension was related to perceptions and the behavioral dimension was related to teachers' intention to act.

The first version of the learning progression and the survey items were subject to change following the item paneling and the cognitive interviews (see Table 4 and Table 5).

4.2. Second Versions of the Learning Progression on Attitudes and the Survey

The second versions of the learning progression and the survey were created following the analysis of data collected through; a) an item paneling and b) cognitive interviews. The item paneling was effective in providing minor revisions to the learning progression levels and the survey items. The cognitive interviews were conducted mainly to make revisions to the survey and increase the quality of the items. Still, the results enabled making revisions to the learning progression levels, as well.

a. Item paneling. Item paneling provided information on how to better revise the learning progression and the survey items. The learning progression and the survey were presented to an expert audience to collect discuss problematic parts and receive their recommendations. The participants of the item paneling were experts on instrument development (n = 1), and on guidance and psychological counseling (n = 3). Recommendations to improve the leaning progression and the survey were revealed following a descriptive summarization of the notes taken.

First, the usage of ABC model of attitudes (Eagly & Chaiken, 1998) in item writing was found positive by the panelists. According to this model, items in the data collection instrument focuses on three aspects; affective, behavior, and cognitive. Another point discussed was about the timing of implementation of the survey. The research is not interested in comparing the attitudes of the teachers before and after the PD program. However, to have more variety in the responses, it was decided to implement the instrument both before and after the PD program implemented at Phase 2 of the current study. The panelists suggested that if the instrument is only administered at the end of the teacher PD program, then the responses of the teachers could be towards higher level responses only. And they also elaborated in the idea that if the survey is only administered before the teacher PD program, then items might not make sense for some of the teachers as they do not have any knowledge or experience with engineering. With administering the survey twice, before and after teacher PD program more number of cases including variety in responses to examine statistically can be reached. This would result in 60 cases as there were 30 teachers participating to the teacher PD program.

Another discussion was around using reverse items. Following a discussion on the issue, writing a few reverse items were recommended. Another point was about the items being easy to agree. It was recommended to try to include more number of harder to agree items. Also it was concluded that the phrase; in-service might be limiting.

In light of this item paneling, the summary of all revisions was noted as: a) writing a few more items that are harder to agree with, b) writing a few reverse items, c) implement the instrument twice both before and after the teacher PD program to get more number of results for the analysis as they can be treated as separate cases, and d) changing the tenses of some of the items to ensure consistency.

Following the item paneling, expert opinion was taken only to refine the “Science Teachers’ Attitudes towards K-12 Engineering Education Survey”, not for making any refinements to the the learning progression levels. Expert opinion was taken from two experts experienced on implementation on engineering design challenges and on survey development. Both of these experts were faculty members who conducted research on STEM education. They were working in two different public universities in Turkey, one of them as a professor and the other one as an assistant professor. Their opinions were taken separately via online. First the survey and the goals of the study were sent to them. Later they sent their detailed suggestions and comments in response again via e-mail.

The first version of the instrument in Table 17 was presented to the experts. Each expert reported their comments and recommendations separately. Following that, all data from the experts were summarized descriptively. In this summarization process, two main categories were created as shown in Table 18: change and removal. In total, 11 items went through either a change or a removal. For the first category, the change in items included changing a word or a phrase. For the second category, removal included removal of a word, phrase or an item in total. Other than these two main categories, experts reported their suggestions on grammatical errors, consistency between items, place of items in the survey, item repetition, and items' relation to attitudes.

The first category, change was mainly concerned with teachers' familiarity with and clarity on the word or the phrase. The experts revealed that teachers may have difficulty in understanding particular words and thus the item. Due to unclear words, items may make teachers think of different things when they are exposed to the same item. One of the changed words ended up to be "workshop" in item 11. It was suggested that this word can create differences between teachers working in public school setting and private school setting.

Table 18. *Summary of Revisions with Expert Opinion*

Items	Change in a word/phrase	Removal of word/phrase/item
Item 1	NA	"Two days on a weekend" due to making the item too specific
Item 2	"Integration"	
Item 3	Adding examples to "sources"	
Item 9	NA	Examples given to problems in the society; "environmental problems, economical problems"
Item 10	NA	Remove "pretty much"
Item 11	"Workshop" to "training and seminars"	Remove the underlined word
Item 14		"To exhibit in a science fair" due to making the item too specific
Item 17	"significant for the improvement of the society" to "impacts society in a positive way"	
Item 21	"inovasyon" to "girişimcilik"	Remove unfamiliar concept; K-12
Item 22	"After school" to "following class hours"	NA
Item 23	NA	Remove full item due to the skill mentioned in the item not directly related to engineering activities

Another example of the same category was for a particular phrase in item 14; "science fair". It was recommended that not all teacher can capture what it means to present an engineering activity at a fair. So this phrase was removed from the item and item 14 was refined. To continue, for item 9, experts commented that the phrase; "economical problems" and its relation to engineering education can cause confusion among the teachers. It was suggested that this phrase might make teachers only think of a very long-term economical reform which clearly needs a lot more then implementing engineering in classrooms. Thus, this phrase that was put as an example in the item in brackets was removed. This was again to the fact that the phrase as it was may be unfamiliar and ambiguous for the teachers. Item 10 formerly included the word "pretty much". The experts recommended that this word alone might direct teachers in answering positively to the item. So this was removed from the item.

Some of the items were revealed to include words/phrases that might limit the thinking of teachers. To set an example, the phrase “two days at weekend” in item 1 was removed from the item following the suggestions of the experts. For item 3, the word; “resources” was found to be confusing. So the experts suggested use of some examples to this word given in brackets. This part was revised as writing examples for “resources” following the recommendations. Lastly, the phrase “innovation” was revised as “entrenepeurship” following the expert opinion. The results of the item paneling and expert opinion were combined for the refinement of the survey items. With these revisions, a refined survey was used in the cognitive interviews.

b. Cognitive Interviews. The cognitive interviews mainly aimed to further increase the quality of the “Science Teachers’ Attitudes towards K-12 Engineering Education Survey” developed in the current study. In particular, the goals of conducting cognitive interviews were to identify ideas for revising the survey with the data collected from science teachers; potential future respondents of the survey. The analysis of the cognitive interviews yielded important findings for specific items and for the survey as a whole. During the cognitive interview, a refined survey following item paneling and expert opinion, composed of 23 items was used (see Appendix H).

The cognitive interviews were conducted with 10 middle school science teachers that participated to a Problem Based STEM Education Workshop for nine days at a public university. As the researcher was one of the guides in this Workshop, teachers were selected based on their convenience to the researcher. They were potential users of the survey in the future; a group that can provide useful information to increase the quality of the survey with their reflections. The two main themes; a) semantics, and b) response task with their underlying codes described the results of the data analysis. Table 19 presented the overall frequency of the codes calculated to appear in the transcripts of teachers. Another comprehensive table, Table 21 illustrated the Codebook for the analysis of data with information on codes and the related items. Following the frequency calculations and identification of codes that received a frequency of five for an item, those items were examined and revised. So with the item wise calculations, items to be revised were revealed.

Table 19. *Themes and Codes with Frequencies*

Codes and themes as they appear in the Codebook	Frequency (#)
1) Semantics	58
Change	46
Situation And Context	12
2) Response Task	90
Unfamiliar	38
Totally familiar	52
Total	148

Theme 1 in cognitive interview results: Semantics

The first theme was concerned with a first level understanding of the items. This theme included two main codes in the final Codebook; change, and situation/context. First, for the code "change", teachers recommended changes to the item where they thought was necessary. At a few points, the interviewer asked in particular for teachers' recommendations for a better written item. However most of the time, the teachers made recommendations for a change without being asked. So in some occasions, the participants themselves recommended revisions for the items, which are important in creation of revised items (Desimone & Le Floch, 2004). For the second code of this theme; "situation/context", teachers provided their opinions on whether the item sounds realistic or to be more specific, whether the item may sound different to teachers due to a particular situation or a context.

The analysis of the interviews revealed that for the first code; "change", teachers mostly drew attention to the phrases "comprehension of engineering" in item 23, "sources" in item 3, and underlined word; "only if" in item 16 and item 19. For the second code; situation-context, the phrase "assigned to another teacher" was revised. To continue, "comprehension of engineering" in item 23 was problematic and required refinement according to teachers' evaluations. In total, five of the teachers commented about how to improve this item. One of the teachers explained:

> *"....Here what should be better is thinking like an engineer, approaching problems like an engineer. The child will not comprehend all engineering content. This is more like something relevant to a real engineer"*

Another noteworthy point was that teachers recommended changes to the underlined word; "only if" appearing in item 16 and item 19. The teachers who commented on this (n = 5) discussed that underlining this word might push teachers to be cautious about the item and tend to strongly agree only due to social desirability. There were also a few (n = 2) who commented that emphasizing this word might raise teachers' attention.

Next, for the phrase; "resources" in item 3, it was highly recommended to revise the examples given for this phrase and add "videos". Teachers believed that inclusion of other sources such as books and journal may not attract teachers' attention and therefore not address their true attitudes. One of the teachers stated:

> *"For this item, when read the example sources books and journals, it is not very attractive to me. Even if I want to examine books and journals, I certainly don't have time for that, books that a lot of time. So if I see videos in among these examples, it is more appealing and realistic to me" "*

The items that were most frequently discussed by the teachers were all in line with another code; "Unfamiliar" under the second theme; Response Task. These were elaborated on as the second theme was described. For the code; "situation/context"; the item and phrase that the teachers most frequently discussed was the phrase "ask for assignment to another teacher" in item 14. Teachers stated that in most public schools the principal of the school do make such requests from teachers as was the case in the item. So it was revealed that this was a realistic scenario for the teachers. However, for the same item, teachers also reported that the situation might depend on whether there are other science teachers working on the school or not ($f = 8$). For the high level of frequency for item 14, revisions were made to this item. According to one of the teachers:

> *"In my school which is a very small school in student numbers, I am the only science teacher working. So this is not possible for my school to ask another science teacher to do what was asked of me…""*

Summarizing the findings expressed with the first theme; Semantics, firsty changes reported by the teachers and, teachers' ideas depending on situation and context were captured. With the findings presented, revisions were made to the survey items. These revisions were depicted in Table 20.

Table 20. *Revisions to the Survey for the First Theme*

Item and/or phrase	Changes made
"Comprehension of engineering" in item23	"Students approching to problems like engineers"
"Assign task to another teacher" in item14	"Avoid the assigned task" appearing in item13
Underlined phrase; "Only if" in item16 and item19	Remove the phrase totally for item16, remove the underline in item19
"Resources" in item3	Add "videos" to the given examples

Theme 2 in cognitive interview results: Response Task

The second theme focused on a second-level understanding. How well each item and the concepts addressed in each item was conceived was the concern. These can be listed as familiarity with words/phrases with two sub-codes which were, unfamiliarity, and total familiarity.

For the code; familiarity, there were two sub-codes. To begin with, the sub-code, unfamiliarity, teacher comprehended the item or a phrase in an item in a completely different way than expected by the researcher. According to Table 20, the items that had a high frequency for this code can be listed as: “in-service training” in item 1, “engineering design education” in various items, and “little effort and time” in item 15.

For item 1, majority of teachers thought of a training provided by Ministry of Education when they thought about “in-service training”. However, the researcher intended to make the teachers inquire about any kind of professional development. So this item was completely understood in a different way. One of the teachers explained:

> *“I directly thought of training provided by the Ministry of Education. In those training, mainly lectures and presentations take place and we listen. This kind of an environment came to my mind*

To continue, with the next item for the phrase “engineering design education” appearing in various questions, the teachers reported that they did not think of engineering applications in K-12 classrooms when they thought over this phrase. In fact, teachers tend to understand this item as a pure engineering application that might take place at a higher education level. Teacher also reported that at such a point, they may not reflect their true attitude. One of the teachers reported:

> *“If I was not at a STEM training right not or if you did not explain to me the goals at the beginning, I would never consider this as referring to a K-12 engineering activity. This expression is more like an undergraduate or advanced engineering to me. I would say disagree to this item.”*

Table 21. *Final Codebook for Cognitive Interview Data Analysis*

Code	Description	Items coded with the code	Items revised
1) SEMANTICS	Problems with how readily the item is understood. First level understanding.		
CHANGE	The place of word is confusing, or there is need for addition or deletion of a word or phrase	1, 3, 6, 7, 9, 14, 15, 16, 18, 19, 20, 22	23, 16, 19, 3
SIT_CON	The situation or the context described in the item is not realistic for the teachers. They believe in reality, there will be a difference which makes the item hard to imagine and reply to.	3, 5, 10, 14, 15,16, 18, 19, 20, 22, 24	14
2) RESPONSE TASK	Problems with retrieving information. How the information in the item is transferred / comprehended as hypothesized. Second level understanding.		
UNFAMILIAR	Teachers understood the concept/phrase/item in a totally different way then assumed by the researchers.	1, 3, 8, 14, 15, 17	1, 15, 4, 8, 11, 13, 16, 21, 23
TOTAL_FAMILIAR	Teachers understood the concept/phrase/item in totally same manner as assumed by the researchers.	1, 3, 4, 5, 6, 7, 8, 11, 13, 14, 11, 16, 17, 19, 20, 21, 22, 24,	16, 18, 7, 19, 22

Again, according to another teacher:

> *"this way as I read it, it is like we will raise engineers. However, my goal should be to enact objectives in the curriculum. This item is like I will tell engineers and factories, but the aim is to implement engineering activities in class."*

For the highly coded second item was item 15 with the phrase "little effort and time". Teachers stated that this might depend on the context and economic situation of the school. If the school has low economic sources, then the teachers might be required to have small amount of materials. Also in terms of time, teachers stated it might depend on the context the amount of time that a teacher might use. One of the teachers expressed:

> *"I am working at a science and art center (BILSEM). So for me time does not matter, I can do an activity for eight hours, I am not ın a rush. But with this item, you can not locate teachers who try to take the easy way out, not sure what this item can measure."*

The researchers as developing this item assumed that having less effort and less time for an engineering activity addressed that the teacher does not have a positive attitude towards engineering activities. However, teachers believed that a teacher may be very positive towards engineering education however, not implementing due to a very busy schedule is not referring to attitude. So teachers comprehended 'less effort and time' as something positive. They thought that such a teacher is ideal, because in a limited time, that teacher is trying for the best. Overall, it was concluded that it was difficult for teachers to understand these three items properly. It was concluded that future respondents may skip responding to these items only because they cannot understand it fully.

The last code in this theme described teachers' complete understanding of the phrase or the item exactly the same way with the researchers. They were very clear to teachers. The most coded item for this sub-code “student club” for item 22, “mandatory situation” for item 19, “certificate” for item 16, and “collaborative work” for item16. All of these were clearly understood by the teachers according to the analysis results. So no revisions were done for these items. It was substantial to be convinced that teachers could understand these items properly. Table 22 summarized the revisions to the survey following the results presented with the second theme; Response Task.

Table 22. *Revisions to the Survey for the Second Theme*

Item and phrase	Changes made
“Engineering design education” in several items	“Integration of engineering to instruction, integration of engineering to science education program, and engineering practices from kindergarden to 12th grade”
“In-service training” in item1	“Education and seminars I can improve professionally”
“Little preparation, effort and time” in item 15	Removal of item due to ambiguity

With the results of the item paneling and cognitive interviews, interpretations to refine the learning progression and the survey on teacher attitudes were summarized. This was followed by the creation of their second versions. With the results of the cognitive interviews, there were two refinements administered to the learning progression levels. To begin with, with cognitive interviews, it was revealed that teachers do not perceive spending more time and effort for preparation of engineering activities as a sign of positive attitude. Teachers explained that even if they are motivated their loaded schedule prevents them. So this part was completely removed from the learning progression levels for future consideration. The phrase; “Only interested in implementing with minimum effort and/or when one is required” was removed. To continue, it was put forth that the phrase “K-12 engineering education” and “engineering and design education” was not properly understood by the teachers.

Teachers thought of a graduate level engineering education and engineering practices with such expressions. Therefore, such expressions were removed from the learning progression levels and replaced with; “integration of engineering to the science program”, “integration of engineering to instruction” and “engineering practices”. As the cognitive interview data was analyzed, the Science Program in Turkey was announced to go through a change. When the draft version of the new program was examined, it was recognized that these expressions were in line with it. This most significance change in the program in terms of the goals of the current study was the inclusion of engineering and design practices. The program clearly states engineering concepts, engineering design principles and engineering practices. Although this new program is not actively carried out in schools yet, it will create more interest in teachers to learn about K-12 engineering education. The second version of the learning progression was presented in Table 23.

For the revisions on the survey; “Science Teachers’ Attitudes towards K-12 Engineering Education Survey”, again the results of the item paneling and the cognitive interviews were effective. As a reminder, for the items that had a low frequency for a particular code in the cognitive interview coding results, no change was done for that item. Only if the item had a high frequency for a particular code, then changes were completed. The second version of the survey prepared to be implemented at the teacher PD program was presented in Table 24. It was also presented in Appendix F as administered to teachers. One of the major revisions in the instrument was the removal of the phrase “engineering and design education” from the items it existed. As discussed in the analysis results section, this phrase made the teachers think of an undergraduate level education on engineering instead of existence of engineering at K-12 level. With these results and going through the new Science Curriculum, this phrase was changed to; “integration of engineering to the science program”, “integration of engineering to instruction” and “engineering practices” “engineering design practices in science education”. As a last point, with close examination of the new announced draft Science Program by the Ministry of Education (MoNE, 2017) four more items were added to the instrument.

Table 23. *Second Version of the Learning Progression on Attitudes*

Increase in positive attitudes
Advocate
Highly interested in learning about engineering practices, integration of engineering to instruction, to science education program and about classroom applications. Highly motivated to improve oneself professionally. Highly interested in implementing engineering design activities and to teach engineering. Likely to strongly agree that engineering practices, and integration of engineering to instruction, to science education helps students to develop and the society to improve.
Supporter
Moderately interested in learning about engineering practices, integration of engineering to instruction, to science education program and about classroom applications. Moderately motivated to improve oneself professionally. Moderately interested in implementing engineering design activities and to teach engineering. Likely to agree that engineering practices, and integration of engineering to instruction, to science education helps students develop and that it helps the society improve.
Neutral
Undecided about learning and improving oneself professionally. Undecided about engineering practices, and integration of engineering to instruction, to science education helping students develop and helping society to improve.
Doubtful
Little interest in learning about engineering practices, integration of engineering to instruction, to science education program and about classroom applications. Little interest in improving oneself professionally. Little motivation to implement engineering design activities and to teach engineering Likely to disagree that engineering practices, and integration of engineering to instruction, to science education helps students develop and that it helps the society improve.
Resistant
Avoids learning about engineering practices, integration of engineering to instruction, to science education program and about classroom applications and improving oneself professionally. Does not want to implement engineering design activities and to teach engineering. Likely to strongly disagree that engineering practices, and integration of engineering to instruction, to science education helps students develop and that it helps the society improve.
Increase in negative attitudes

Table 24. *Second Version of the Items*

Second version of the items of the survey
1.I am interested in participating to training and seminars on integration of engineering design process to instruction to improve professionally.
2.I believe that implementation of engineering design activities in our classrooms can increase students' interest in technology and engineering careers.
3.I am interested in sources (e.g. books, journals, videos, other visuals) on engineering design practices in science instruction
4. I feel excited to learn more on engineering design activities I can implement in my class.
5.I think engineering design activities can improve students' team working skills
6. Integration of engineering to science instruction from kindergarten level to 12th grade level can impact our society in a positive way.
7.I enjoy investigating exemplary engineering design challenges.
8.I think it is significant for students to improve their engineering and design skills.
9. I believe that kindergarten level to 12th grade level should include engineering practices.
10.I feel motivated to teach engineering design process.
11.Integration of engineering design to science instruction is significant
12. I think engineering design activities can improve students' creative thinking skills
13.If my school administration asks me to prepare an engineering design activity, I can avoid the responsibility.
14. I am interested in participating to a training or seminar on engineering design practices to receive a certificate of participation.
15. Integration of engineering to science instruction will impact the students in a positive way.
16. Integration of engineering to science instruction from kindergarten level to 12th grade level helps students to understand the interdisciplinary approach.
17. Integration of engineering to science will contribute to the solutions of societal problems.
18. I am interested in implementing engineering activities when I am required.
19. I believe that integration of engineering to science instruction from kindergarten level to 12th grade level helps to develop students' innovative thinking.
20. Engineering design activities are important for students to transfer knowledge to a product.
21. I am motivated to have a student club where I can implement engineering design activities
22. I find it important for my students to approach problems like an engineer.

4.3. Third Versions of the Teacher Learning Progression and Survey on Attitudes

The third version of the learning progression was created following the analysis of the collected with the survey at the teacher PD program. The survey was administered at the teacher PD program that was implemented at Phase 2 of the methodology framework of the study (see Figure 7). For the administration of the survey, its second version, which was put forth following the literature search, written assessments, item paneling, and cognitive interviews was used that was presented in Table 24.

In selection of the participant teachers to the teacher PD program, certain criteria were followed that was elaborated on in Chapter 3; Methodology. Following these criteria, 30 middle school science teachers were selected among the applications. The criteria followed to select teachers to the teacher PD program were: a) level of participation to STEM and/or engineering design teacher professional development programs before, b) level of knowledge on engineering design process, c) gender, d) city in Turkey, e) experience in teaching, and finally f) school type as public or private. The participant 30 teachers filled in the survey both one week before the teacher PD program, and at the second and last day of the teacher PD program. For the statistical analysis, data coming from both administrations were used. However, due to missing responses of four cases, in total, 56 cases were examined with the R Studio statistical program following a Rasch analysis in the third building block of construct modeling framework (Wilson, 2005).

In examination of the data collected with the survey; and the survey; “Science Teachers’ Attitudes towards K-12 Engineering Education Survey”, various reliability and validity estimates were produced. This were elaborated on in the following section as their examination revealed the third version of the learning progression on teacher attitudes.

The analysis of the data focused separately on the reliability measures, validity measures and the overall fit of the items in relation to the respondents; the teachers. For reliability measures, internal consistency reliability coefficient; Cronbach's Alpha was derived separately for items and respondents (Cohen et al., 2007).

There were four sources of validity evidence; evidence based on instrument content, evidence based on response processes, evidence based on internal structure, and evidence based on consequences of using an instrument (Wilson, 2005). In preparation of the instrument, several steps were followed in line with the construct modeling framework. To sum up, following a Rasch analysis provided the evidence on reliability, validity, and information of the empirical alignment between the learning progression and the survey.

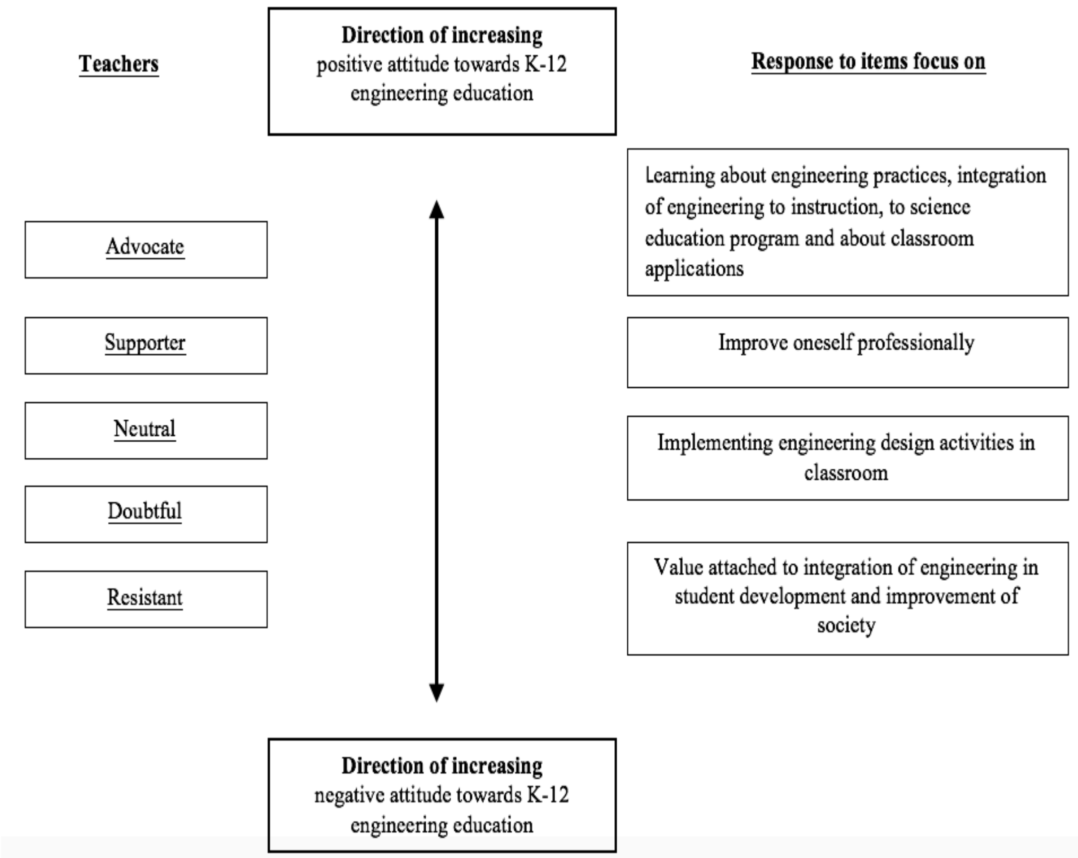


Figure 17. Alternative depiction for the LP and items

Figure 17 depicted an alternative for the learning progression on teachers' attitudes towards K-12 engineering education. The levels from highly negative attitude; resistant to highly positive attitude; advocate can be examined in the figure as they range between direction of increasing positive attitude and direction of increasing negative attitude. The right side of the figure summarized the aspects of teachers' attitudes as they were mainly revealed with literature search and results of the written assessments.

Wright maps are part of the outputs of the data analysis with R studio for the construct modeling measurement framework. Wright Maps produce validity evidence for the internal structure of the learning progression and the survey. The Wright maps presented the relation of item difficulty to teacher ability. For the purposes of this analysis, as the construct studies was teacher attitudes, high ability stood for teachers' more positive attitudes. Likewise, low ability stood for teachers' more negative attitudes. The wright map provided teachers' abilities or locations; tendencies to score high and low responses for the items with locations of items on the same scale.

For a Rasch analysis, the item and person separation statistics provide the researcher with information on the quality of separation. If the separation is too wide, this points to gaps between item difficulties and respondent abilities. And if the separation is too narrow, this means that there is not sufficient differentiation between item difficulties and respondent abilities (Wright & Stone, 1999). The item separation reliability, that is how well the items were separated to identify the direction of the construct, and finally, the person separation reliability, that is how efficiently the set of items can separate the teachers being measured will be documented. The Wright maps were considered evidence of whether the teachers' selecting a response was related to their estimated place on the construct map representing their attitudes towards K-12 engineering education.

To begin with, a comparison between results of two different statistical analyses was completed. The first analyses results belonged to running the statistical analysis based on the results of both pre-test and post-test in that the total number of cases was 56. The pre-rest referred to the administration of the survey before the teacher PD program, and post-test referred to the administration of the survey on the last day of the teacher PD program. The second analyses results belonged to running the statistical analysis based on the results of only the pre-test. This time the number of cases was 30, as there were 30 teacher participating to the teacher PD program. The reason for the case number in post-tests to be 26 was because, four of the cases in this group included too many incomplete items in the survey.

Figure 18 depicted the Wright map for the first case (n = 56), and Figure 19 presented the Wright map for the second case (n = 30). Some critical differences were observed when the two wright maps were closely examined. The left hand side of both figures represented the teachers shown as bar graphs. The blue dots stood for the items on the survey, presented with the letter “q” for “question” and their number on the survey. For example, “q15” addressed question or item 15 on the survey. At the bottom part of the Wright Maps, the levels of the learning progression ranging from doubtful to advocate can be observed. Finally, the very right part of the Wright Maps showed the Logits. The logits stand for the probabilities of both item difficulty and respondent ability; tendency to score. It can be said that the Logit is a uni-dimensional measure unit (Nguyen & Griffin, 2013). More information on these representations by Logits were provided in the following sections when the items and respondents were examined in detail.

For both figures, black dashed lines were later added to address the range of respondents; teachers. The critical finding revealed with the comparison of these figures was that, when the case number was 30, less number of items were left beneath the dashed line, the set of respondents; teachers. When the case number was 56, there were more number of items left beneath the dashed lines. The area covered between

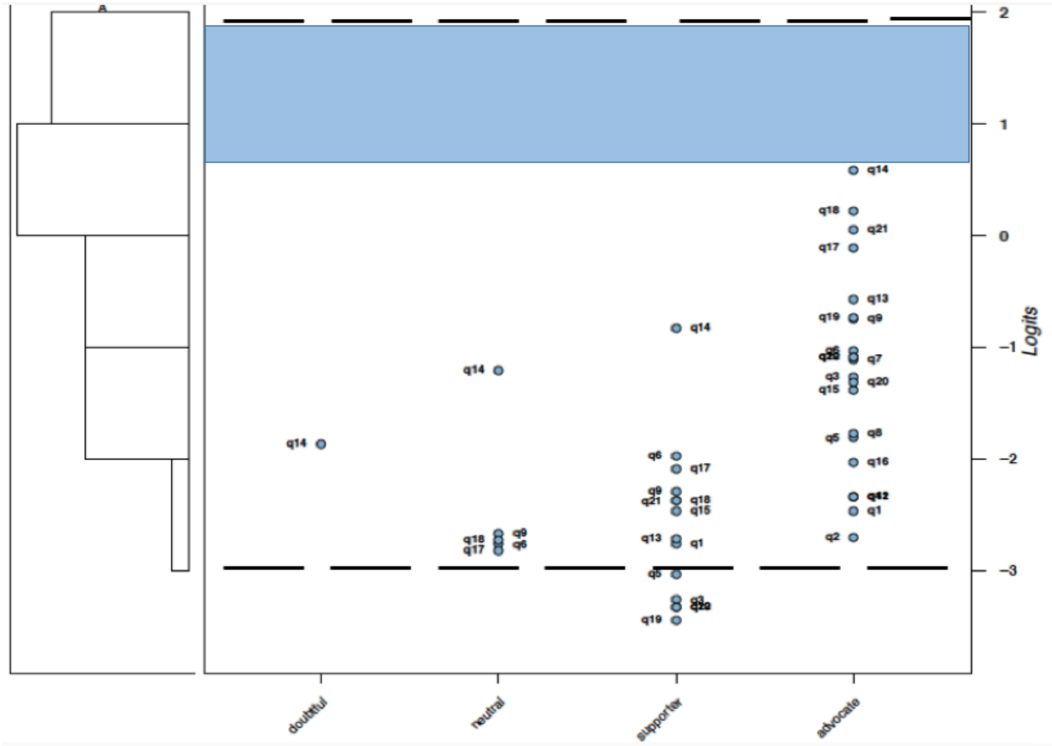


Figure 18. Wright Map based on 30 cases

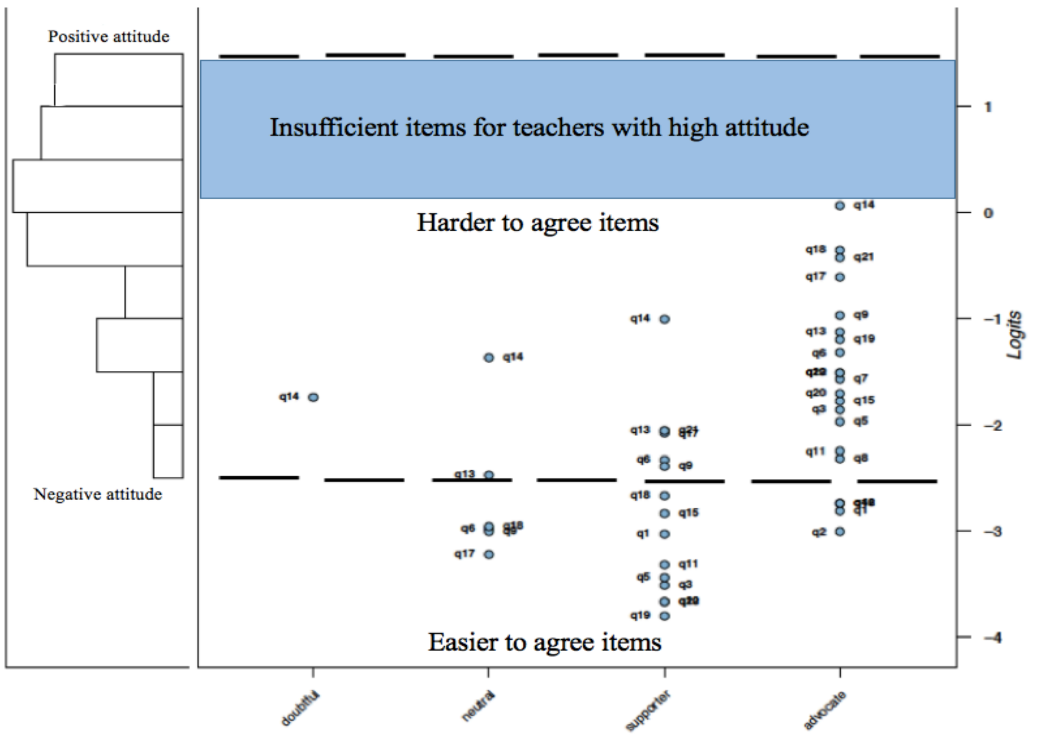


Figure 19. Wright map based on 56 cases

the dashed lines indicate the range that the respondents; teaches are represented by the item set. Moving from these points, it can be concluded that when the case number is 30, the teachers are better represented by the item set However, when the case number is 56, there are more items left out outside the dashed lines.

A shared finding in both figures was that, the area above q14; the hardest item to agree with was too large. This meant that, there were respondents that were not represented by the item set at all. This area was depicted with a blue shade in both figures. Again for both figures, one when the case number is 30, and the other one when the case number is 56, there are both positive and problematic issue in terms of the analysis results. However, as the wright map revealed, when the case number is 30, teachers' tendencies to score; teacher ability, and item difficulty are better aligned. Still because the current study was interested in examining the results of both pre-test and post-test administrations, the rest of the results were presented based on the case number of 56. The Wright Map depiction when the case is number is only composed of pre-test results was only for comparison purpose.

To emphasize one of the critical aspects of the Wright Map, among the items pointed with blue dots, the items on the top are more difficult; harder to agree, and the items at the bottom part are easier; easier to agree. So for the items at the bottom, that was where majority of the items accumulated, it was easy for the teachers to respond to them as strongly agree. The Wright Map presents the findings in a way that helps understand the probability estimates of both the teachers and the items on one common figure. The left side of the Map shows where the respondents are located in terms of ability; teachers' level of attitude. Teachers with higher positive attitudes were shown in higher positions whereas teachers with negative attitudes were shown in lower positions. The right side of the Map shows where the items are located. Items that reflected a more positive attitude were shown in higher positions and items that reflected a more negative attitude were shown in lower positions.

Overall, both the respondents and the items are presented on a Logit scale. For a particular case, teachers with the same attitude scores as the item difficulty (agreeableness of the item) had a 50% chance of confirming or agreeing with the item. Where a person is located at the same location as an item, is where a teacher has a 50% probability of answering it at that level. The difference between the teachers' attitude (proficiency) and the item's difficulty is the logarithm of the odds of a higher level response; strongly agree to that particular item by that teacher. This is identified by a statistical model (NRC, 2014).

When the Wright Map (see Figure 20) was closely examined with the red and blue arrows added to the figure, critical findings were revealed. The Logit scale locates the teachers and the items in a common scale of teachers' attitudes and the difficulty of the items. Here again, difficulty of an item refer to its being more harder to agree.

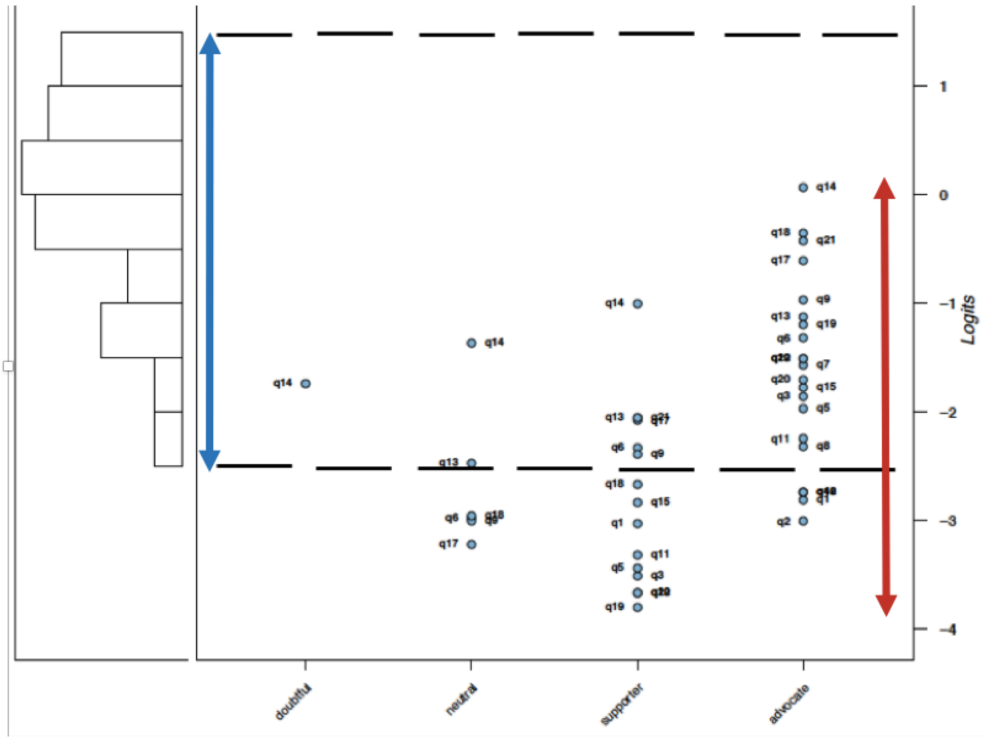


Figure 20. Estimated locations of items and teachers

The red arrow depicted the range of the items; item difficulty or their being easy or hard to agree. The blue arrow presented the range of teachers; their attitude levels. The range of the teachers' attitude levels were from around -2.5 Logits to +1.5 logits, with a mean ability level of 0.87 logits and a standard deviation of 0.13. Whereas the item difficulty; the agreeablesness of the items ranged between – 3.80 Logits and + 0.11 Logits with a a standard deviation of 0.16. This firstly indicated that the items did not sufficiently target the attitude levels of this particular sample of teachers. In other words, the items did not cover the spectrum of teachers well. However location of items having similar location with a set of respondents is an ideal result (Wilson et al., 2006).

The match between items and levels was weak, meaning that the overall the items were not "difficult" at all. Here "difficult" stands for the difficulty in agreeableness of the item. In other words, broadly, the items were not harder to agree, instead they were very easy to agree and choose the highest level of response category, *strongly agree*.

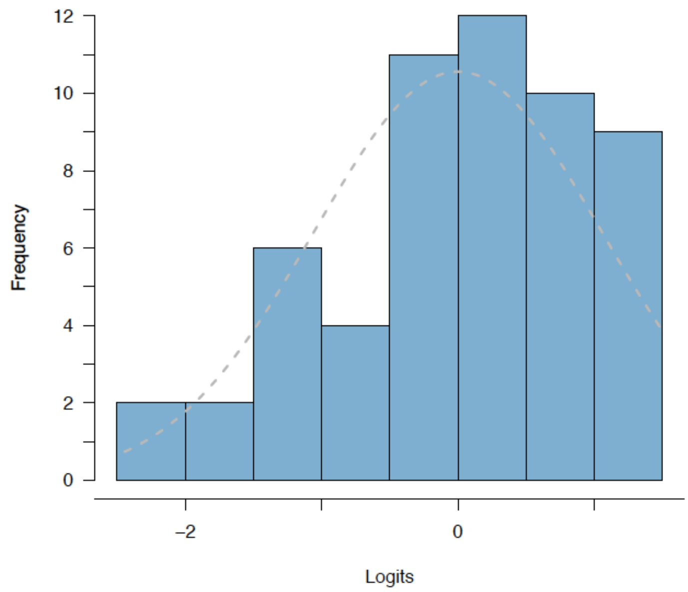


Figure 21. Person estimations

The locations of the teachers on the Wright Map were positioned too high compared to the items. So there were more respondents who were able to answer the items at all ability levels, than if they were doubtful for example. This was also evident in the histogram of the estimated teacher locations with a normal curve overlaid in Figure 21. The distribution of the teachers among the levels was negatively skewed distribution as opposed to a normal distribution. This finding again evidenced the teachers' accumulation on the more positive attitude end of the continuum represented by the learning progression. However, for an ideal distribution, a normal curve around 1.0 Logits was expected. This would signify majority of teachers' accumulation at around 1.0 Logits.

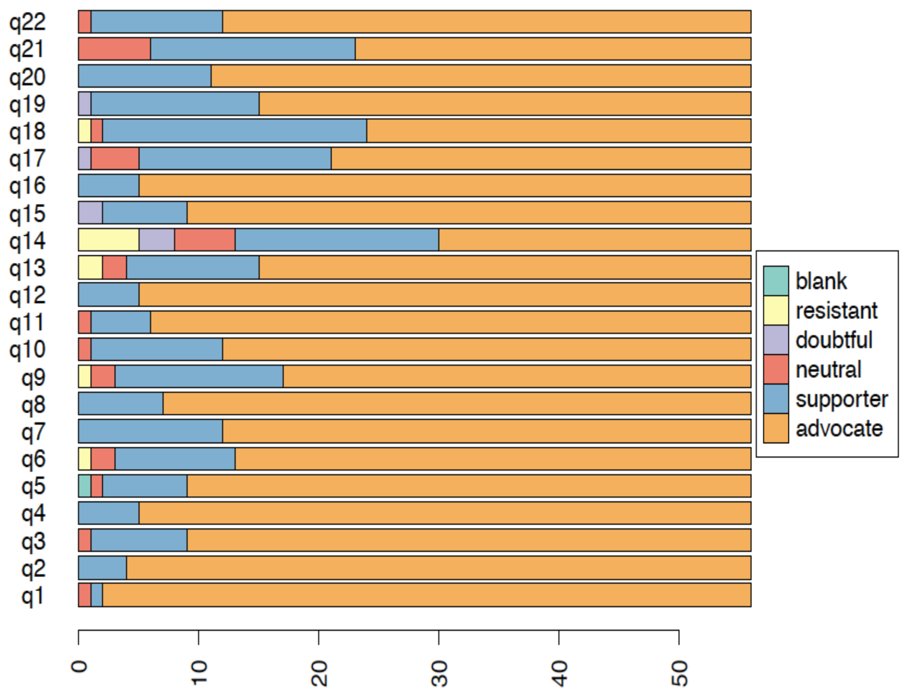


Figure 22. Score distributions by item

Figure 22 provided more information of the score distributions of the teachers by item. When these descriptive results of the scores were examined, a big majority of the responses accumulated in levels 4 and 5. It was assumed that there would be more responses at the lower levels as well; level 1 (resistant) and level 2 (doubtful). To provide more detailed information with examples, for item 1 there were 54 teachers at the advocate category, one teacher at the supporter category and one teacher at the neutral category. This item was the one that included more number of teachers at one single category. As a second example, for item 2, again there was a great accumulation on one single category. In total 52 teachers were at the advocate category, and the remaining four teachers at the supporter category. For the item level validity, it was expected that participants higher on the construct would score higher on each of the items.

The score distributions, histogram on teacher location estimates and the Wright Map all documented teachers' accumulation towards positive attitude and as a response category; agree and strongly agree. Overall, some of the items that failed to create any variety in responses were items 1, 2, 4, and 16. These were items with many missing response categories demonstrated items with missing response categories; for having all answers with an attitude of supporter and advocate. Items that included responses to at least three response categories were 5, 6, 9, 10, 11, 13, 14, 17, 18, 21 and 22. A striking finding was that there was only one item that included all five response categories; item14 and again only one item that included four response categories, item13. So these two items seemed to be harder to agree for the teachers compared to the rest of the items. Lastly, items 6, 9, 13, and 18 elicited answers that were "resistant" but not doubtful and might be useful to investigate to see if there is reason to suggest why participants would respond that way. The findings presented on Figure 22 were in line with the Wright Map in terms of the items' location ranging from easy to agree to harder to agree.

Next, the distribution of the items within the levels was examined and found to be roughly normal (see Figure 23). There was a trend of increase obtained from left to the right part of the Wright Map to some degree. Nonetheless, there were many issues on item locations that distorted the trend.

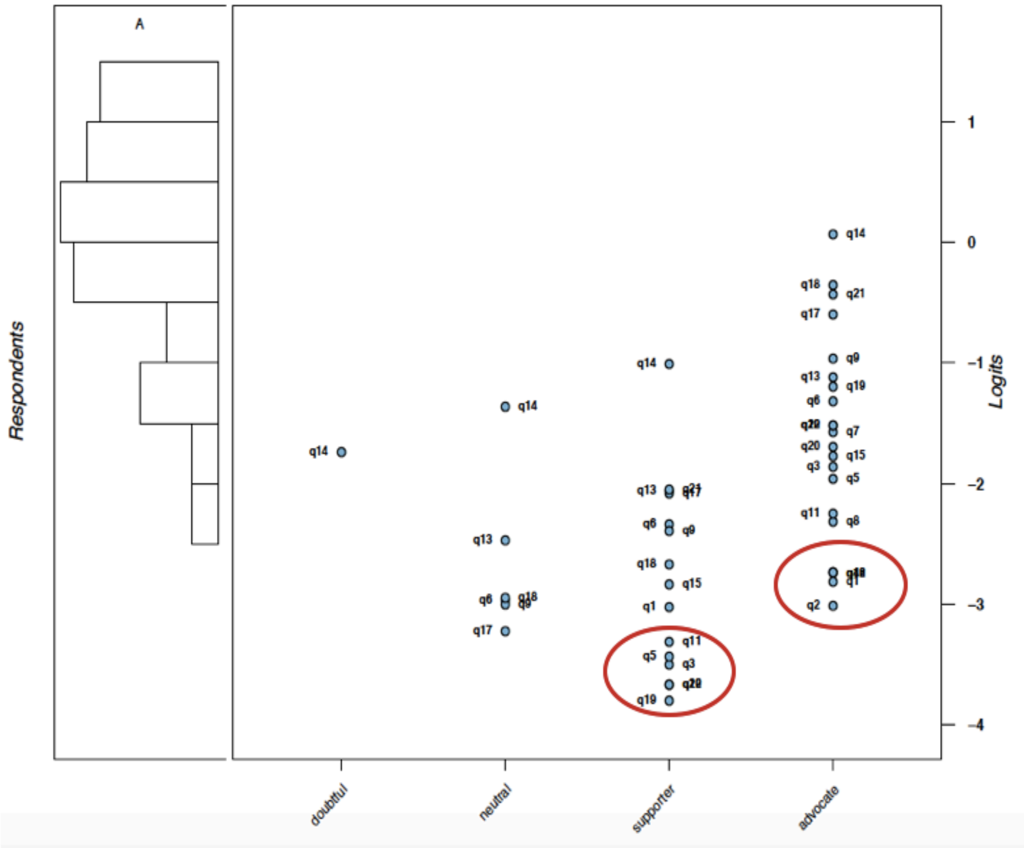


Figure 23. Distribution of items within levels

On the figure, group of items circled can be recognized. Without the two group of items in circles, the rest of the Wright Map presented a better pattern in increasing from the left part to the right map. This increase again signified items' distribution from easy to agree to harder to agree. For example, only one of the items; item14 elicited teachers' responses on their attitudes at Level 1. So it is especially difficult to make conclusions about Level 1. As the next substantial finding, there were several points of overlap of items, in particular for items 6, 9, 17, 18, 19, and 21. This indicated that these questions were more ambiguous for respondents at that ability; or attitude level.

Item Thresholds were presented with a second Wright Map as seen in Figure 24. The left part of the Wright Map showed the distribution of teachers' attitude estimated and the right part showed the distribution of item thresholds. For every item, there were four thresholds possible, since the survey had five response categories; ranging from strongly disagree to strongly agree. These four thresholds, represented by tt_1, tt-2, tt_3, and tt_4 stood for the transitions between Level 1 and Level 2, Level 2 and Level 3, Level 3 and Level 4, and Level 4 and Level 5 respectively. The left part depicted the distribution of the teachers along the cosntruct; attitude from resistant to advocate, in Logits. The right part represented the items' locations in relation to teachers' locations. Zero Logit represented overall teacher mean attitude which was 0.87.

The thresholds present a teacher's estimated location to have a probability of 50% to respond at that level or below. The Wright Map based on thresholds help to examine the relation between the difficulties of the items; their being easy or harder to agree with and the levels of respondents; teachers. To set an example to read the figure, for item1, there are only two thresholds; tt_1 and tt_2, although the item had five response categories and four possible item thresholds. This depiction with only two thresholds on the Wright Map was due to the fact that, nobody answered "resistant" or "doubtful" so there were only three categories of responses for item 1; two thresholds. They were depicted as 1 and 2 even though they indicated thresholds between levels 5 and 5 and 4 and 3. So this item was one of the easiest to agree items. Similar items with only one or two thresholds instead of four were items 2, 19, 20, 8, 4, 3. Items 13, 14, 18, and 9 were found to have at least three thresholds meaning that these items represented the learning progression levels well.

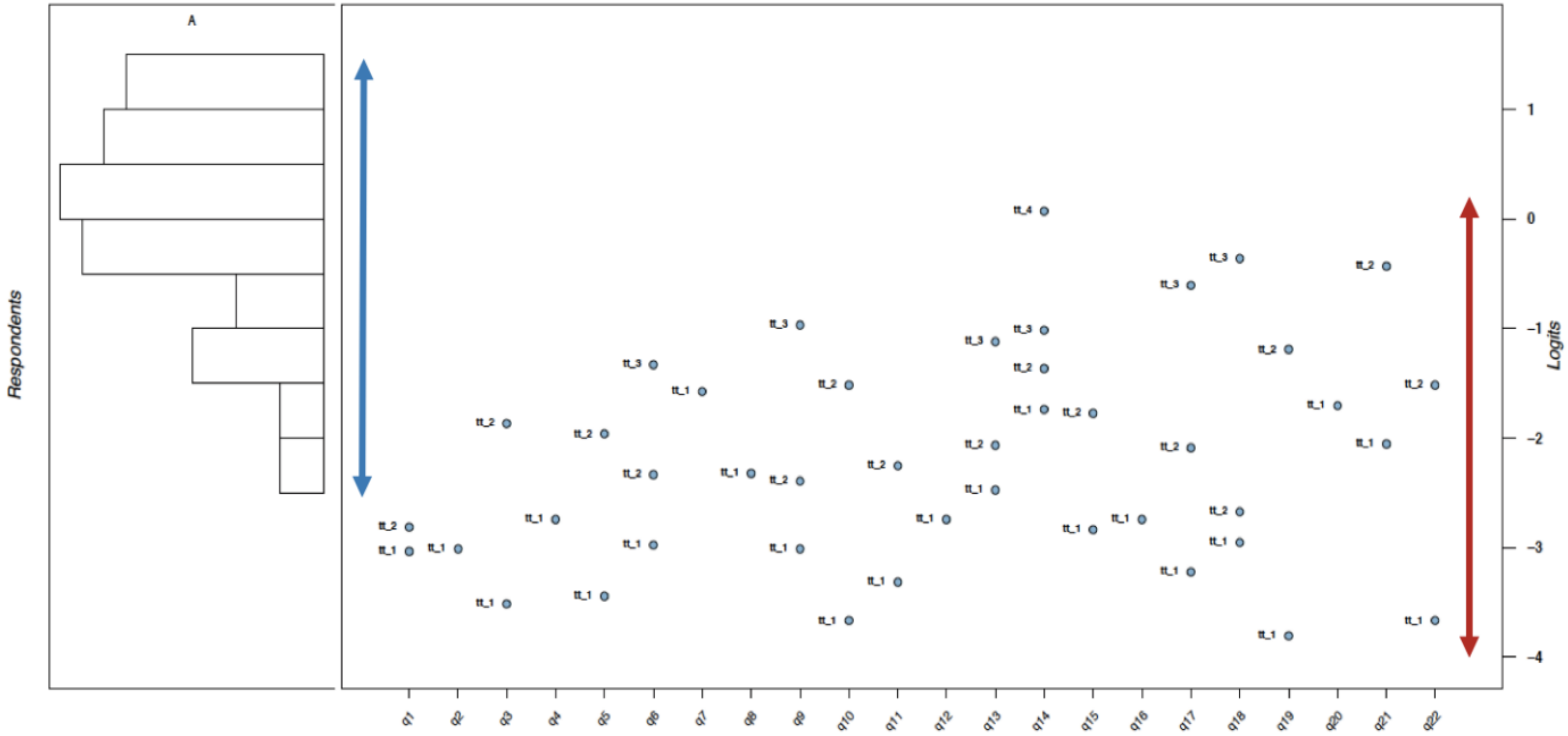


Figure 24. Item Threshold Wright Map

Item threshold's distribution (arrow on right) extended the distribution of respondents (arrow on left) indicating the item thresholds could not cover the teacher attitudes well. One significant conclusion of this was that the survey was not successful at measuring outlying teachers. One example item threshold Wright Map by Jin et al. (2015) was presented in Figure 25 which addressed a better alignment between the learning progression and the items the authors developed.

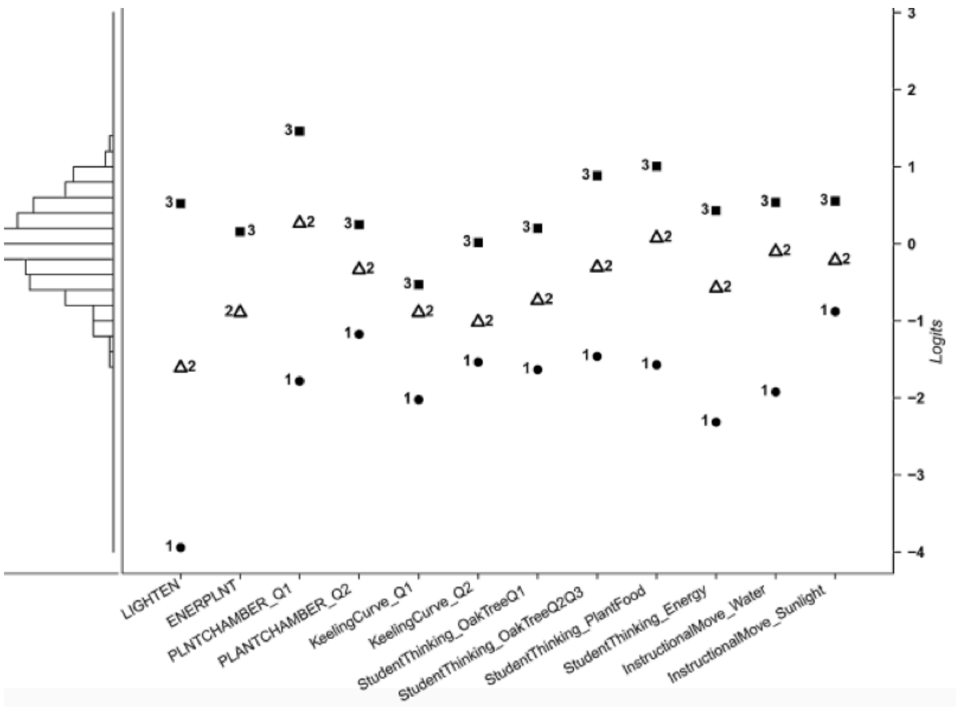


Figure 25. Example item threshold Wright Map (Jin et al., 2015)

As an example interpretation of Figure 21, a teacher whose attitude location estimate is the same as the fourth threshold of item14, which is around Logit 0, then the teacher has a 50% possibility of getting at Level 5 (advocate). A teacher whose attitude estimate is above the same threshold has more than 50% probability of scoring at that level or above.

The result of the data analysis revealed both item and person separation reliabilities of the attitude variable (see Figure 26). The item separation reliability or the coefficient alpha that showed the internal consistency was found to be .84. This value was considered acceptable as it was above .70. The coefficient between .80 - .90 is usually treated highly reliable and coefficient between .70 - .79 is accepted as reliable (Cohen et al., 2007). This meant that the items in the survey were measuring as expected. The person separation reliability was calculated to be .78 which was again acceptable.

Number of respondents	56	56	55
Number of items	22	22	22
IRT model	PCM	NA	NA
Number of iterations	168	NA	NA
Integration points	21	NA	NA
Deviance	1268.064936	NA	NA
AIC	1358.064936	NA	NA
BIC	1449.205762	NA	NA
Mean raw score (proportion)	0.866322665	0.865665584	0.867355372
Standard deviation raw score	0.131878249	0.132257517	0.132865026
Missing data %	0.081168831	0	0
Cronbach's Alpha	NA	0.841727148	0.845679082
Person separation reliability	0.77724177	NA	NA

Figure 26. Data analysis output on reliability

With the results of the Rasch analysis, items that showed infit and misfit were revealed. The item fit statistics represents the item discrimination indices. The separation of the items within certain limits is critical for construct validity (Wright & Masters, 1982). The item fit presents the difference in the teachers' expected score and their actual score. According to Wilson (2005), the reasonable fit should be between .75 and 1.33. Figure 27 demonstrated the mean square fit statistics of the 22 items on the survey. The rectangular area indicated the well-fitting items.

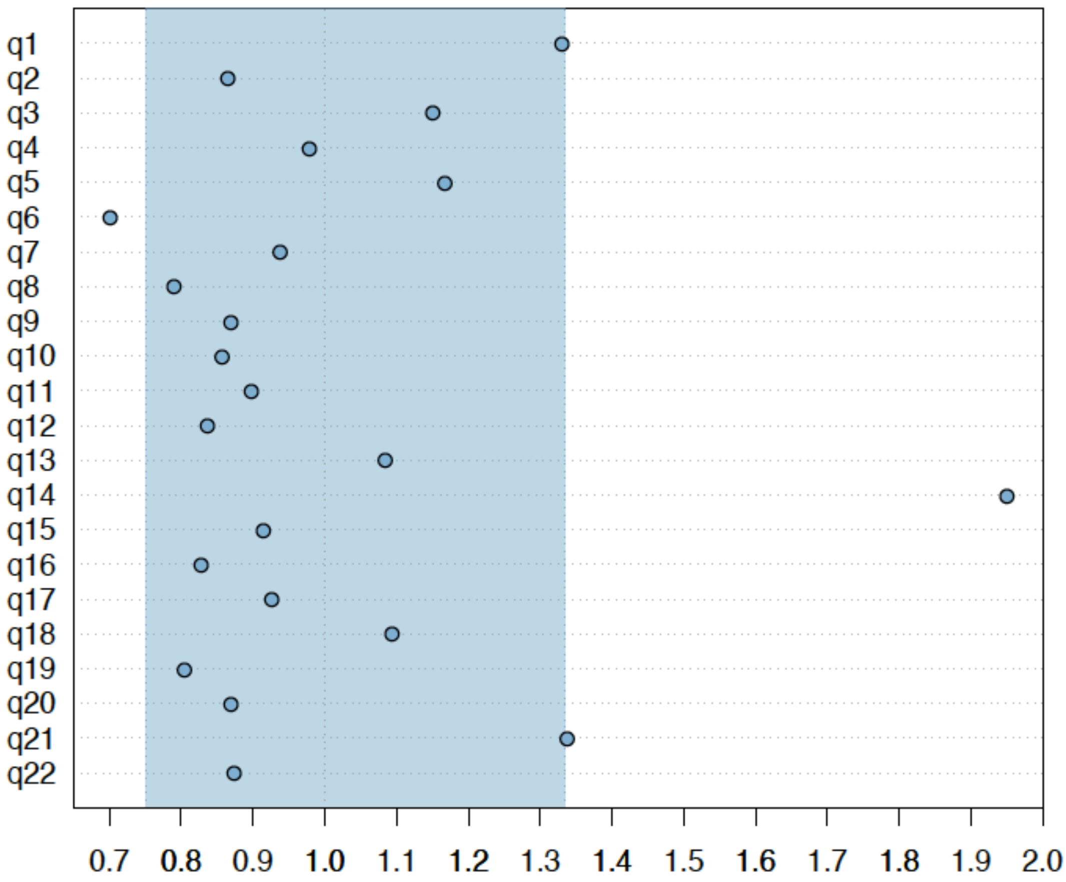


Figure 27. Item mean square fit statistics

When the weighted mean square fit statistics (Wright and Masters, 1982) for item parameter estimates are closely investigated, it is observed that most of the items are functioning well. Weighted mean statistics of most of the items are found to be in the confidence interval. Table 25 presented the weighted infit statistics for all items. The items that were observed to fall outside the critical interval .75 and 1.33 were items 6, 14, 1, and 22. This results led to the interpretation that one should be really careful about these items however there is not enough evidence to directly throw them away. Still for explaining the misfit of the items, they can be investigated closely which can improve the reliability of the survey.

Table 25. *Weighted Fit Statistics*

Items	Item infit
1.I am interested in participating to training and seminars on integration of engineering design process to instruction to improve professionally.	1,33
2.I believe that implementation of engineering design activities in our classrooms can increase students' interest in technology and engineering careers.	0.86
3.I am interested in sources (e.g. books, journals, videos, other visuals) on engineering design practices in science instruction.	0.56
4.I feel excited to learn more on engineering design activities I can implement in my class.	0.97
5.I think engineering design activities can improve students' team working skills.	1.16
6.Integration of engineering to science instruction from kindergarten level to 12^{th} grade level can impact our society in a positive way.	0.70
7.I enjoy investigating exemplary engineering design challenges.	0.93
8.I think it is significant for students to improve their engineering and design skills.	0.79
9.I believe that kindergarten level to 12^{th} grade level curriculum should include engineering practices.	0.86
10.I feel motivated to teach engineering design process.	0.85
11.Integration of engineering design to science instruction is significant.	0.89
12.I think engineering design activities can improve students' creative thinking skills.	0.83

Items	Item infit
13.If my school administration asks me to prepare an engineering design activity, I can avoid the responsibility.	1.08
14.I am interested in participating to a seminar on engineering design practices to receive a certificate of participation.	1.95
15.Integration of engineering to science instruction will impact the students in a positive way.	0.91
16.Integration of engineering to science instruction from kindergarten level to 12^{th} grade level helps students to understand the interdisciplinary approach.	0.82
17.Integration of engineering to science instruction will contribute to the solutions of societal problems.	0.92
18.I am interested in implementing engineering activities when I am required.	1.09
19.I believe that integration of engineering to science instruction from kindergarten level to 12^{th} grade level helps to develop students' innovative thinking skills.	0.80
20.Engineering design activities are important for students to transfer knowledge to a product.	0.86
21.I am motivated to have a student club where I can implement engineering design activities.	1.33
22.I find it important for my students to approach problems like an engineer.	0.87

The standard error of measurement (SEM) refers to how accurate each estimate of the items and the teachers were. SEM is critical to for understanding the usefulness of the estimated locations and make further interpretations. Figure 28 depicted the SEM for the results. It was observed that relationship between the Logits and the stand error was not a U-shape. This showed that the teachers on the more positive attitude side of the learning progression will have more items near them than those respondents at the middle and the negative attitude side. The SEM is ideally a U-shape figure which signifies a better empirical alignment between the learning progression and the survey items.

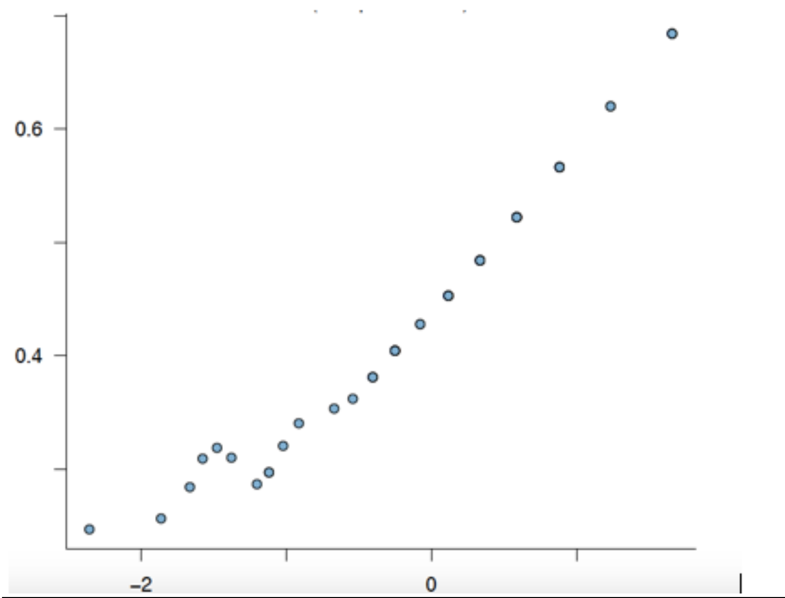


Figure 28. Standard error of measurement

When the results were combined and examined more closely, it was noticed that overall a fairly good reliability and validity evidence was attained. However, there are issues of reconsideration that requires some of the items. When the results from item fit analysis and Wright Maps were examined together, removal and/or modification of some items were considered. To begin with, items 1, 2, 4, and 16 were among the ones the easiest to agree with; teachers all approached with the same response category to these items which was strongly agree. As reported, most of these items also had misfit statistics in that they were not successful in including separate and at least two item thresholds.

The items revisited closely were:

Item1 I am interested in participating to training and seminars on integration of engineering design process to instruction to improve professionally.

Item7 I enjoy investigating exemplary engineering design challenges.

Item21 I am motivated to have a student club where I can implement engineering design activities

Item2 I believe that implementation of engineering design activities in our classrooms can increase students' interest in technology and engineering careers

Item16 Integration of engineering to science instruction from kindergarten level to 12th grade level helps students to understand the interdisciplinary approach.

When the items were considered together, two group of commonalities were recognized. First group of items, items 1, 2, 7, 21 were all concerned with teachers; motivation to improve themselves professionally in K-12 engineering education. A possible reason for the misfit and issues on estimate could be that as engineering practices is a new and very interesting topic for teachers, they are all interested in improving themselves. For the second group of items, they all focused on the role of engineering in improving students. So these items were not sufficient to tap into lower levels of the learning progression. There might be more items, or these items can be refined to make teachers not agree easily on different impact of engineering on students.

As item 14 was very successful in terms of its thresholds and overall item fit, it was examined as well. The item included a part on receiving a certificate. Maybe some of the teachers though the item is asking, the only reason to participate to a teacher PD program is to get a certificate. So the variety in this item might be due to its being ambiguous as well. Still, better items similar to item 14 can be added to the survey. As item14 was successful in terms of its thresholds and overall item fit, it was examined as well. The item included a part on receiving a certificate. Maybe some of the teachers though the item is asking, the only reason to participate to a teacher PD program is to get a certificate. So the variety in this item might be due to its being ambiguous as well.

To continue analysis of items, the following items 6, 11, 16, 17 were found to be easy to agree, thus not creating a variety in responses and also not successful in terms of the thresholds of the items. It was suspected that teachers might have approached to these items as if they were facts because these items included the similar structure as the following; "integration of………" can impact in a positive way/is significant/ contribute to students and society". Therefore, these items were not successful in terms of tapping onto teachers' attitudes well. Lastly the items; 4, 10, and 21 had a relatively more successful performance which were concerned with teachers' actual performance and teaching engineering to students.

For the first impressions, since most teachers accumulated at the higher levels of the learning progression and there were many items that were not successful in separating teachers to the levels of the learning progression, some revisions were made on the learning progression. Firstly, since the items on interest and motivation on learning about engineering and integration of engineering to instruction were easy to agree and not successful in item difficulty, this aspect of the learning progression was only evident in the three levels of the learning progression instead of five levels. So this was considered an aspect easier to agree and put at the lower three levels of the learning progression only. The higher levels; level 4 and level 5 did not include interest and motivation towards learning. Likewise, when it comes to teachers' positive attitudes in terms of the value they attach to engineering for improving students and the society, items were not successful in creating an ability; agreeableness distribution. Therefore, this aspect was kept to reflect only up to three levels. Teachers' interest in improving themselves professionally was kept as the same because the number of items around this aspect was lower so it was decided to be tested again in future studies. To continue, the items that focused on behavior and on

Table 26. *Third Version of the Learning Progression on Attitudes*

Increase in positive attitudes
Advocate
Highly motivated to improve oneself professionally. Highly interested in implementing engineering design activities and to teach engineering. Considers school context (time and effort necessary) and possible barriers and highly interested in implementing engineering activities.
Supporter
Moderately motivated to improve oneself professionally. Moderately interested in implementing engineering design activities and to teach engineering. Considers school context (time and effort necessary) and possible barriers and moderately interested in implementing engineering activities.
Neutral
Somewhat motivated to improve oneself professionally. Somewhat interested in implementing engineering design activities with students. Highly interested in learning about engineering practices, integration of engineering to instruction, to science education program and about classroom applications. Likely to agree that engineering practices, and integration of engineering to instruction helps students develop and that it helps the society improve. Is not sure about the role of school context (time and effort necessary) as a barrier
Doubtful
Little interest in improving oneself professionally. Little motivation to implement engineering design activities with students Somewhat interest in learning about engineering practices, integration of engineering to instruction, to science education program and about classroom applications. Undecided about engineering practices, and integration of engineering to instruction helping students develop and the society improve. Considers the school context (time and effort necessary) as a serious barrier
Resistant
Avoids learning about engineering practices, integration of engineering to instruction, to science education program and about classroom applications and improving oneself. Does not want to implement engineering design engineering design activities with students. Likely to disagree that engineering practices, and integration of engineering to instruction helps students develop and that it helps the society improve.
Increase in negative attitudes

teachers' motivation to implement engineering activities, to expose their students to engineering in formal and informal environments were relatively harder to agree with according to the results of the study. So this part of the learning progression was also kept the same way. Third version of the learning progression was illustrated in Table 26.

In line with the results of the data analysis and the third version of the learning progression, the refinements to the survey to create its final version were: a) deletion of the unsuccessfully performing items, b) refinements in the outcome space; scoring of items, c) addition of more items on aspects of teacher attitudes that reflected teaching, and on teachers' professional development and finally, d) addition of Guttman type items. The final version of the survey can be examined in Appendix I.

First, the items that were successfully performing based on various outputs of data analysis were identified. The most poorly performing items in terms of their alignment with the learning progressions and in creating a variety in terms of responses were revealed to be Items 2, 4, 11, and 16. To continue, there were also slight problems with the overall performance of Items 1, 19, 2, and 11. However, only items that were unsuccessful to a large extent were directly revealed. The rest were decided to be tried more with several administrations, so they were kept.

Overall findings showed that, teachers mostly found it relatively easy to agree with items on interest in learning about engineering and about the contribution of engineering to the students and the society. Whereas, teachers found it relatively difficult to agree with the items on motivation to implement engineering activities and expose their students to engineering, and on improving themselves professionally. The levels of the third version of the learning progression were refined accordingly. Considering the refinements in the learning progression levels, the outcome spaces for scoring should also be refined. Outcomes spaces show the relationship of the items and their scoring according to the learning progression levels (Wilson, 2005). For the final version of the survey, there are two outcome spaces, the first one for the items on interest in learning and on improving oneself professionally, and the second one for the items on contribution of engineering for students and the society, and motivation to implement and motivation to implement engineering activities and expose their students to engineering, and on improving themselves professionally. For the items in relation to the first outcome space only included three categories. This was due to the fact that, there are three levels on the refined learning progression for these aspects. Still the survey will continue to have five response categories, but two of the response categories will be in line with the new lowest level of the learning progression. This outcome space was provided in Table 27. For the items in relation to the outcome space, outcome space previously used (see Table 16) can again be utilized.

As the next refinement, five more items on teaching engineering, and two more items on motivation to improve oneself professionally; teachers' professional development were added to the survey as these aspects were more successful in reaching a differentiation in teachers' attitudes. These newly added items were adapted from surveys on teacher attitudes; two items by Yu et al. (2012), one item by Lachapelle et al. (2014), two items by Hart and Laher (2015), and two items by Van Aalderen-Smeets and Van Der Molen (2013). The number of items on teaching engineering can be even more increased in future versions of the survey, once the teacher PD program delivered will have follow-ups where teachers will gain experience on teaching engineering.

Table 27. *Newly Emerged Outcome Space*

Response Choice	Score	Level on the learning progression
Strongly agree	3	Neutral K-12 engineering education
Agree Undecided	2	Doubtful to K-12 engineering education
Disagree Strongly disagree	1	Resistant to K-12 engineering education

As a last point about the survey, a new item type was introduced; Guttman items. Gutman type scale items are used in attitude instruments (Page-Bucci, 2003; Fidelis, 2017). Guttman type items can also be stated as cumulative items where respondent chooses the option that applies the best. Although they are useful, such items might be challenging to construct (Page-Bucci, 2003). With addition of such items, respondent teachers might be distinguished better which will result in the enhance validity of the learning progression. With use of Gutman type items in addition to Likert-type items, item responses included more detail compared to having only statements on agree or disagree. With use of Gutman items, for the abovementioned aspects that teachers found easy to agree for the most part, teachers can be forced to think more and the survey can capture their attitudes more successfully. The final version of the survey included 10 Gutman type items and 24 Likert-type items.

With all the refinements outlined, the final version of the survey might better align with the learning progression levels in future administration and data collection. The reflections on the refinement of the learning progression, and the survey with future recommendations were discussed in Chapter 5; Discussion.

The second major section reported the first, second and the third versions of the learning progression on teachers' engineering design process understanding respectively. The following research questions was answered; "What levels do science teachers typically experience as they move from a novice to a more sophisticated understanding of the engineering design process?"

4.4. First Version of the Teacher Learning Progression on Engineering Design Understanding

First version of the learning progression was created following the results of the; a) literature search, and b) written assessments. A literature search was conducted and data collection with written assessments were completed.

a. Literature search. Middle and lower levels of the learning progression were defined, based exclusively upon the research findings that reported how transition from a naive to a higher understanding of the engineering design process takes place. What needed to be investigated was how the transition occurs from a naive understanding towards a mastery level understanding of the engineering design process. In order to access an informing literature sources to construct the initial version of the middle and lower levels, again the three phases adapted from the systematic literature methodology of Borrego et al. (2015) was utilized. The three phases were: 1) Search; to retrieve the studies, 2) Selection; to apply inclusion criteria, and 3) Synthesis; to reach an overall summary of the included articles. For the first phase, a search was conducted in the databases; Ebscohost, Google Scholar, and Web of Science. The key search terms that resulted in the most relevant and useful studies were "engineering design process" in combination with "teacher knowledge", "change in engineering design process knowledge/understanding", "assessing engineering design process knowledge", "engineering design understanding rubric", "conceptions of engineering design process" and "misconceptions" in combination with "engineering design process". The search was again limited with studies published during a 16-year period from 2000 to 2016. The databases were carefully examined to access studies that can inform the first version of the learning progression on the changes in engineering design process understanding. This phase resulted in 87 articles following the removal of duplicates and the ones that could not be reached as full-text. As a next step, an initial screening of the selected 87 articles, some of them were eliminated due to having focuses irrelevant to the goals of the search. These irrelevant focuses were engineering design process as used in pure engineering disciplines, and change in engineering design performance, rather than knowledge and understanding.

In total, two inclusion criteria were applied to retrieve the most useful studies for the goals of developing the learning progression. These inclusion criteria were: 1) to have change in engineering design process knowledge/understanding or misconceptions on engineering design as a focus, and 2) to have K-12 students, engineering faculty students, and teachers as participants. Literature that described engineering design for students was also included due to two reasons. Firstly, there was a lack of sufficient research on teachers' understanding of engineering design. And secondly, engineering design was new to teaches and the advanced level they can reach is considered to be similar to what is expected of students. Especially in Turkish context, due to teachers' unfamiliarity with the engineering education and the engineering design process, it was concluded that literature on students' engineering design understanding can also guide the learning progression. The elimination among the accessed studies with the three inclusion criteria resulted in 18 studies in total that can guide the development of the middle and lower levels of the learning progression. Detailed information on these studies were shown in Table 28.

There were two group of studies presented in Table 28 useful in understanding the change or the transition among engineering understanding that were presented under "changes in engineering design and/or engineering design process understanding". This group was further divided into two groups based on how they worked on the change in engineering design understanding. Among the first group; categorization of achievement levels; 10 studies were revealed to create categorizations of achievement levels to assess their participants' engineering design process understanding. One example can be presented from Hynes (2012). According to this study, there were three achievement levels, which were naive, middle and expert which depicted an example of the changes as the understanding gets more sophisticated. The teachers in the naive level were only expected to state the names of the engineering design process steps. As the transition to the middle level occurs, teachers were expected to explain each step and provide an example for them.

To continue, Duncan et al. (2011) choose to put teachers on achievement levels based on the revised taxonomy levels of Bloom (1956). As teachers move from the lower levels to the higher levels, they start to develop their own ideas, make evaluations and judgments on engineering design processes also considering criteria and standards. The exemplary transitions from lower levels to middle and higher levels were very useful to inform the developed learning progression on engineering design understanding.

The second group; presentation of a rubric; used a rubric to assess the engineering design understanding of their participants. These rubrics focused on differentiating aspects. For example, the rubric by Nadelson (2015) included five design elements that were scored separately. However, three of these elements were based on the performance and application of the participants. So only two of the design elements; problem statement and criteria and constraints were useful for the current study. As a second example the rubric by Fantz et al. (2010), included four score points for 10 different aspects of the engineering design which contained the engineering design process steps and elements of the engineering design such as decision making, criteria, constraints and optimization. Studies presented under; misconceptions related to engineering design were helpful in especially constructing the lower level of the learning progression.

Table 28. *Informative Literature on Engineering Design*

		Change in knowledge/understanding		
Authors	Year	Categorizations of achievement levels	Presentation of a rubric	Misconceptions related to engineering design
Hynes	2010	x		
Baker	2007	x		
Duncan	2011	x		x
Bailey	2006	x		
Crimsoned	2013			x
Oehlberg	2011			x
Hsu	2010		x	
Nadelson	2015		x	
Fantz	2011		x	
Baker	2006		x	
Newstetter	2001	x		
Wendell	2014	x		
Song	2012	x		
Becker	2015	x		
Cross	2004	x		
Ahmed	2003	x		

The relative difficulty of engineering design understanding addressed in the examined sources along with a logical consideration (Alonzo & Steele, 2009) helped with brainstorming on the organization of the levels. To summarize, the relative hypothetical differences of teachers' understanding of the engineering design process based on the literature, a logical consideration, and finally initial interviews with teachers helped with the final organization of the levels of the construct maps. Also the engineering design process descriptions in Table 1, and the engineering design process models by Boston

Museum of Science (Cunningham, 2009) and Massachusetts Engineering Framework (Massachusetts Department of Education, 2006) were helpful in construction of the levels of the first version of the learning progression.

The common points in the examined studies revealed commonalities to include as the levels of the learning progression from low to high were constructed. To summarize, the lower levels were mainly created based on empirical findings from the written assessments and the literature search findings were influential in creating both the highest level; the upper anchor and the transition from lower levels towards the higher levels (Alonzo & Steedle, 2009). The final decisions on what to include in the learning progression levels were given following the examination of results of the written assessments.

b. Written Assessments. The results of the written assessments were especially helpful in understanding how the lower and middle levels can be generated. Although the results of the written assessments were useful, it was concluded that they did not make much of a change; the findings of the previous step; literature search was more influential. The written assessments were conducted with the same teachers that responded to the written assessments on attitudes. These included 14 in-service middle school science teachers, working in Turkey. Teachers filled in the written assessments online. The goal of collecting data with written assessments was to investigate teachers' initial understanding of the engineering design process. The findings obtained with the written assessment had a guiding role in developing the levels of the learning progression framework. In the first step, the written assessments were scanned to detect some emerging codes. These emerging codes were carefully noted. All emerging codes identified can be reviewed in Table 29.

Table 29. *List of Emerging Codes for Engineering Design*

Emergent codes
Engineering design cycle
Tradeoffs
Process of design
Prototype
Programming
Modeling
Testing
Constraints
Criteria
Teachers' facilitation
Preparation of materials
Revision
Iterations

Following the first step, major commonalities between the written assessments were identified. This step was guided both by the list of emerging codes and a through reading of the written articles. In the final and third step, frequency calculations was completed over the final list of codes and themes. According to the frequencies calculated, the low frequency codes were interpreted as harder to achieve and understand. In line with the same logic, the high frequency items were interpreted as easier for teachers to achieve. Therefore, these codes were interpreted as belonging to the lower level of the learning progression. As for the results, two main themes emerged; a) engineering design concepts, and b) engineering design process. There were codes under both themes as can be examined again in Table 30.

Table 30. *Results for the Written Assessments for Engineering Design*

Themes and codes	Frequencies	Summary of findings
Engineering design concepts		The engineering design concepts that teachers have knowledge on were use of materials, product and design, and use of scientific knowledge
Use of materials	21	
Product and design	10	
Use of scientific knowledge	11	
Engineering design process		In terms of the engineering design process steps teachers had knowledge on only prototyping, testing and conducting research
Prototype	9	
Testing	10	
Conducting research	17	

Theme 1 in written assessments: Engineering design concepts. Under the first theme; engineering design concepts, it was revealed that the teachers had knowledge on use of materials during the process ($f = 21$), the role of product and design ($f = 10$), and the necessity to use scientific knowledge ($f = 7$). These can be summarized as procedures or products completed a during engineering design process. They were referred to as concepts critical to know as one is involved in the engineering design process.

> *"....in order to have products at the end of this process, such engineering activities and practices should be significant part of science education"*

Teachers seemed clear about the role of product and that engineering design process is completed with a product. One of the teachers reported that

Another point that teachers commonly were aware of was the existence of a design in this process. A teacher expressed this by the following:

> *"products and material design is critical components of engineering design process. If students do not create designs, engineering design process will be incomplete."*

Although majority of teachers (n = 11) mentioned product and design in their written responses they had a confusion between product and design. Teachers seemed to use design and product interchangeably. To continue with the next code; use of scientific knowledge, this knowledge was evident in majority of teachers' (n = 10) responses. According to one of the teachers:

> *"students brainstorm and make observations on which science knowledge they will use. This is the process where knowledge is transformed to product and new products are created. Creation of product is a critical distinction from classical science instruction.*

To summarize for this theme, teachers were found to have an initial knowledge on only a few of the procedures and concepts related to the engineering design; products and design, use of scientific knowledge, and use of material. Other critical concepts related to engineering design such as criteria, constraints, optimization and tradeoff (Moore et al., 2014; NRC, 2012). Only 3 of the teachers could provide explanations related to criteria, constrains and their role in the engineering design process.

Theme 2 in written assessments: Engineering design process. This code referred to teachers' initial knowledge on the steps of the engineering design process and the process as a whole. Teachers were revealed to have an initial knowledge on prototype, testing, preparing prototype, and conducting research as steps of the engineering design process. So the rest of the steps; identify the problem, develop possible solutions, select the best solution, communicate solutions and revising solution were not mentioned by the teachers (Massachusetts Department of Education, 2006). Or according to another engineering design process model, teachers did not discuss ask, imagine and improve (Cunningham, 2009). Majority of teachers utilized examples or definitions for testing. One of the teachers reported:

> *".....students can test their proposed solutions only with engineering design activities, students can only experience this test with engineering to me. This is a clear distinction from science instruction."*

These two themes and the codes within the themes reflected the aspects of engineering design that the teachers were found to have an initial knowledge on. It was revealed that the teachers had knowledge on only a few of the engineering design concepts and they were not knowledgeable on engineering design process steps. They were only aware of a few steps which were, conducting a research, making a prototype, and testing the design. So having knowledge on only a few steps and concepts of the engineering design was considered as lower level indicator. However, having knowledge on more of the steps and concepts of the engineering design was considered as higher level indicator.

The results of the written assessments together with the literature findings, were influential in creating the learning progression. Some findings were parallel in both the literature and the written assessment results. These were directly mentioned in the learning progression. To summarize, the first version of the learning progression was based on; a) literature search, b) analysis of written assessments, and c) a logical consideration of proximity to lower and higher levels (Alonzo & Steedle, 2009). The first version of the learning progression can be observed in Table 31.

4.5. Second Version of the Teacher Learning Progression on Engineering Design Understanding

Item paneling. During item paneling, the first version of the learning progression was presented to the panelists. This was followed by questions, comments and a discussion. And finally panelists agree on some of the recommendations. Through the process, the researcher took detailed field notes which were summarized below.

Table 31. *First Version of the LP on Engineering Design*

More sophisticated understanding
Complex
The engineering design process steps and an engineering design process model are clear Purpose of each engineering design process phase is clearly understood. Constraints, criteria, tradeoffs, refinements are clear Are using accurate scientific evidence in their explanations, and understand the assumptions used to construct designs, provide rationale for the explanations and existence of each concept/phase. Compare the potential of different solutions Can understand complex problems' relation to issues of global and/or local significance Can provide examples to design challenges
Intermediate
Can articulate on some of the engineering design process steps Only has some initial ideas on a few steps of the engineering design process; testing, conducting research. Developing a more coherent understanding that engineering design process is made of phases and the arrangements of these phases related to the success of a design.
Novice
Not grasped the ideas and concepts, need help to start Articulate their ideas about engineering design process by using prior experiences, observation, not scientific evidence. Some concepts such as product and design, use of materials, use of scientific knowledge and their relation to engineering design process are clear Understands engineering design process has phases. Confusion between scientific method and engineering design process. Insufficient steps in the engineering design process
No apparent understanding

The participants of the item paneling on teacher understanding of the engineering design process included experts; PhD students studying on curriculum and instruction (n = 2), and a professor at a public university in USA experienced on STEM and engineering design (n = 1). One of the recommendations by the panelists was to put a separate section on each level that reflects common errors of teachers. This was said to help better distinguish the levels from each other.

One of the panelists strongly suggested to think this learning progression more of an explanatory attempt. This meant that it was suggested to keep the levels flexible and put as much as information available. It was discussed that with the data analysis of teacher logs and clinical interviews in the next sections, the learning progression will eventually turn into an empirically-based form. So the panelists agreed that at this point, keeping much information at the levels, without much simplification can work better. This might cause increasing the number of levels, too. Eventually it will be more simple with data analysis at the implementation of the teacher PD program. To continue, one of the panelists recommended that a teacher with an advanced understanding can probably know more than one engineering design process models. So putting this information in the higher level if the learning progression was discussed. Another addition agreed upon recommendation was referring to evaluation of a complete engineering design process model in the levels. The panelists agreed on the higher difficulty level of being able to understand criteria, constraint, and tradeoff. They also believed that these engineering design concepts should stay at the higher levels. Another critical guidance was on stating the name of the engineering design steps separately within the levels.

A final recommendation highlighted by the panelists was about the implementation of the teacher logs in the next stage to further collect data and refine the learning progression. The panelists suggested to implement the easier questions on the teacher logs at the end of the first day, and implement the more challenging questions on the teacher logs at the end of the second day.

With guidance taken from the item paneling, the summary of refinements around the learning progression were noted as: a) containing more detailed information in the levels, b) putting information on comparison of different engineering design process levels on the highest level, d) putting information on evaluation of an engineering design process, e) implementation of the teacher logs on two separate days of the teacher PD program, and f) attention to problem solving process at the lower level. Upon these results, the second version of the learning progression can be examined in Table 32.

Table 32. *Second Version of the LP on Engineering Design*

More sophisticated understanding
Mastery
Teacher understands the application of all the engineering design process steps; define problem, research the problem, develop possible solutions, select the best possible solution, construct a prototype, test, redesign, and marketing. Teacher can also understand certain engineering concepts necessary to complete the engineering design process; criteria, constraints, and how criteria is prioritized with trade-offs. Teacher can evaluate complete design processes with weaknesses and strengths with regard to engineering design process steps. Can compare different engineering design process models (e.g. Cunningham, 2009; Massachusetts Department of Education, 2006) Design process is iterative.
Advanced
Teacher recognizes that there are systematic steps of the engineering design process that have certain names: define problem, research the problem, develop possible solutions, select the best possible solution, construct a prototype, test, redesign, and marketing. Teacher can understand more of engineering design process steps beyond problem identification, prototyping and designing. Common errors: Confusion between criteria & constraints and their identification Problems with identifying and explaining prioritization & trade-offs
Intermediate
Teacher recognizes that engineering design process consists of steps in solving problems and meeting the needs. However not all steps are understood, there is lack of understanding with regard to the steps. Teacher may believe that these steps only include problem/need identification, possible solutions with design and product. Teacher can understand one or two of the steps. Mostly teachers are aware of the modeling / prototyping and problem identification steps Common errors: Confusion between scientific method and engineering design process. Experiments, observations and analyzing results are thought of as engineering design process steps Insufficient steps in the engineering design process Daily language instead of certain terminology related to engineering design process
Novice
Teacher understands the engineering design process as a problem solving process, a process for meeting needs. Teacher might recognize the existence of a design during the process. Teacher believes it is a process where different disciplines collaborate to solve a problem Teacher believes the process starts with a problem and ends with a design Common errors No knowledge on particular steps of the engineering design process.
No apparent understanding

4.6. Third Version of the Teacher Learning Progression on Engineering Design Understanding

Third version of the learning progression was created following the results of the; a) teacher logs and b) clinical interviews. Data was collected with these two data sources through the teacher PD program implemented at Phase 2 of the methodology framework of the study (see Figure 8). In total 30 middle school science teachers constituted the participants of the teacher PD program. These teachers were selected based on particular criteria: a) level of participation to STEM and/or engineering design teacher professional development programs before, b) level of knowledge on engineering design process, c) gender, d) city in Turkey, e) experience in teaching, and finally f) school type as public or private. The first two criteria were critically important to have participants who represented different levels of understanding of the engineering design process. The participant teachers included 10 novice teachers, 10 intermediate teachers, and 10 expert teachers (see Table 9 and Table 10).

The participant teachers completed the teacher logs both at the end of first day and at the end of the second and the final day. Accounts of all PD participants; 30 teachers were analyzed. The clinical interviews were conducted with teachers the week following the completion of the PD program. Data coming from 10 teachers' interviews following the PD program were analyzed. The data collected with the two data sources were analyzed to generate the third version of the learning progression. First the results of the data analysis for teacher logs were presented. This was followed by the results of the data analysis for clinical interviews.

a. Teacher Logs. First, coding rubrics were developed for each corresponding task on the teacher logs. The coding rubric for each task included indicators specified for each achievement level, example responses from the teachers and the particular differentiations between the above and/or below level(s). These coding rubrics particular to each task provided elaborated descriptions for the four levels of the learning progression framework. The relation between the task, the learning progression levels, and exemplar responses were presented clearly. The coding rubrics were composed of four achievement levels as the case for the learning progression. The lower levels of the coding rubrics were created with the data analysis of accounts of novice teachers, the middle levels of the rubrics were created with the data analysis of accounts of intermediate teachers, and finally the higher levels of the rubrics were created with the data analysis of accounts of expert teachers. Sometimes for example, responses of expert teachers also helped with the middle levels. So the accounts of three groups of teachers were examined separately. For novice group teachers, analysis was made based on nine teachers' accounts as one teachers' responses included many missing parts.

Coding rubric for the first task of the teacher logs

Novice level teachers

The first coding rubric was generated based on the analysis of the responses of teachers (n = 9) on the first task of the Teacher Logs. The coding rubric for the first task was presented in Table 33. As another commonality among the low level of teachers was that, they had confusions between the scientific method and the engineering design process and the goals of these two (n = 5). This conclusion was reached by the mistaken placement of teachers for question 4 on this task. As stated, five of the teachers placed making observations, making experiments as steps of the engineering design process. Therefore, it was concluded that teachers were not clear about the steps followed in the engineering design process and distracted by irrelevant strategies. Although there were also teachers in this group who were very clear about their distinction.

A point quite confusing for the teachers was their expectation of turning the product into a technology as one of the steps of the engineering design process. This was another distractor for Question 4 and it was observed that majority of the teachers thought of this as a necessary step. An outstanding finding was that almost all of the teachers (n = 8) could not complete the last five steps of the engineering design model in Question 4. Only one teacher had these last five steps correctly placed in her model.

Table 33. *Coding Rubric for First Task*

Levels	Specific level description
Level4	Connection between engineering design process and real life problems is made. Most steps of the engineering design process model are in order correctly. Confusions continue to exist on the engineering design steps testing, evaluation, presenting, and revision.
Level3	Mention of constraints such as quality, usability and feasibility in the engineering design process model. A new product is revealed or an already existing product is revised with engineering design process. The order or steps include many mistakes. Confusions still with testing, evaluating, revising, presenting and marketing are missing.
Level2	Engineering design process is a systematic process with certain steps. The order or steps include many mistakes. Teachers understand the process is repeated, that is it is iterative. Confusions with engineering design process model, testing, evaluating, revising, presenting and marketing are missing Many mistakes in the order of the engineering design process steps
Level 1	Engineering design process is a problem solving process. A new product is revealed. Confusions with scientific method and engineering design process

It was revealed that the lowest level responses did not refer to the engineering design process with its steps. However, as they depicted on the engineering design model, they were mostly clear about the beginning steps of the engineering design process, identification of the problem, conduction research and working on solutions. They could not complete the engineering design model correctly for the remaining steps. When it came to the initial steps of the engineering design model, identification of the problem, conducting research and providing possible solutions, five of the teachers placed these three steps correctly.

Teachers in this group mentioned the importance of revisions and learning from mistakes (n = 5). This was interpreted as teachers had some emerging understanding on the iterative nature of the engineering design process. Almost none of the teachers in this group implicitly or explicitly mentioned critical concepts related to the engineering design process; criteria, constraints and tradeoffs. Still it was detected that five of the teachers had responses including the systematic nature of engineering design that follows certain steps.

Intermediate level teachers

Next the accounts of the teachers that belonged to the intermediate level of understanding were examined. One of the remarkable common point was the mention of revision, improvement, and/refinement of an existing product (n = 6). So it was recognized that teachers' accounts focused on moving in the engineering design cycle more than one time in order to revise a product. This was a distinction from the lower levels in that, there was not mention of working on the engineering design process multiple times for revisions on the products. Teachers seemed aware that one can move flexibly with the engineering design process (n = 7). This was interpreted as teachers' emerging understanding on the nonlinearity of engineering design which is a critical distinction from the scientific method.

The most commonly used phrase in these accounts was "refinement" (n = 3). This was also evident in their comments on *learning from mistakes* as commented by one of the teachers. Teachers seemed clear about starting the engineering design process with an already existing product to make refinements. Teachers were still found to be confused with the final steps of the engineering design process. Almost all teachers (n = 9) were confused with the steps from four to eight. Only one of the teachers correctly filled in these steps.

Majority of the teachers (n = 8) did not place any scientific method related distractors in their engineering design models. Still one of them put making observations and the other one out making experiments in their models. To continue, five of the teachers put "collaboration of disciplines" as one of the engineering design process steps in their model. The collaboration of disciplines is critical for engineering design process however it is not one of the steps in the model. Another commonality was about the order of the steps. Teachers in this group had more number of correctly ordered steps compared to the lower understanding group. But still, teachers seemed confused about putting the engineering design steps in the correct order.

A differentiating point for this group of teachers was their implicit mention of engineering design concept; constraints (n = 5). Teachers started giving examples to constraints which can be listed as money, functionality, usability. In total, two of the teachers made a connection between engineering design process and real life problems, and bringing solutions to impact daily life. Their statements can be reported as; “solutions to daily life problems”, and “identification of problems with needs of the current time”

Expert level teachers

According to the accounts of teachers, half them discussed the connection of engineering design process with real life problems. Some of the phrases teachers reported in relation to this point were:

> *“problems in the nature, responding to needs of individuals, solutions to make life easier, realistic needs*

Another commonalty was the mention tradeoff strategy by the teachers (n = 5). Teachers were examined to use almost the same phrase as they discussed this strategy in their written responses:

> *“best solutions with least amount of materials, maximum efficiency with minimum price..”*

So teachers were revealed not to produce alternative understanding on the tradeoff strategy. Teachers at this level were also confused about the last three steps of the engineering design process (n = 7). Teachers were revealed to realize the goal of engineering design process as both solving problems and meeting needs together (n = 5). This was a clear distinction from the intermediate and the lower levels. For the high understanding group of teachers, it was found out that mostly did not have

mistaken order of steps in their engineering design process models. None of the had any scientific method process steps in their models. In total four of the teachers mentioned the engineering design process as a systematic process with clear steps.
A critical finding was that five of the teachers mentioned the significance of presentation and marketing after the emergence of a product.

Coding rubric for the second task of the teacher logs

The first coding rubric was generated based on the analysis of the responses of teachers on the first task of the Teacher Logs. The coding rubric for the second task was presented in Table 34.

Novice level teachers

With respect to the second task of the written assessments, half of the teachers (n = 5) that belonged to the lower level of understanding used many irrelevant steps as part of the engineering design process. Some of these irrelevant steps they mentioned in their engineering design process steps were:

> *"research........., innovation, identifying general characteristics, pre-test and post-test, relating"*

Majority of teachers in this group (n = 6) were found to start their engineering design process with the correct step that is the identification of problems. Although these teachers mentioned many of the remaining steps in describing the engineering design process, one of the teachers only wrote two steps in total; identification of the problem and solving the problem, which is incorrect and incomplete.

Table 34. *Coding Rubric for Second Task*

Levels	Specific level description
Level4	No mention of irrelevant or incorrect steps in engineering design process steps description Only few errors in order of the steps. Correct understanding of almost all engineering design process steps. Correct definitions and examples to both concepts Variety in examples of criteria and constraints. Examples include engineering design challenges they were exposed to.
Level3	Correct understanding of more than the first two steps of the engineering design process. Still some of the steps are missing. Less mistakes in the order of the steps. Number of mistakes are less than three. Correct definitions for both concepts. Correct example for at least one. Example for constraints limited to budget.
Level2	Correct understanding of the first step of the engineering design; problem identification and providing multiple solutions. Many mistakes regarding the order of the steps. Incorrect steps do not include any irrelevant strategies
Level 1	Mention of irrelevant strategies within the engineering design process steps. Correct understanding of the first step of the engineering design; problem identification. Rest of the steps are mostly missing. No correct definitions and examples for engineering design concepts; constraints and criteria

Among this group of teachers, two of them confused scientific method again as they described the engineering design process. This was evident in their mentioning of “hypothesis, experimenting, and scientific process”. When it comes to Question 7 and Question 8 in the second task, the teachers in this group had much difficulty in providing correct responses (n = 7). In total seven of the teachers could not provide any correct definition for both “criteria” and “constraints”. For one of these teachers, he only tried to define “constraint” as “limitation” which is only paraphrasing with one simple word. For four of the teachers they could provide correct examples for criteria and constraints both. One of them provided really good definitions and also examples to both concepts:

> *"constraints are the limitations/barriers during design process, whereas criteria are the thinkgs that needs to be met, the basic factors to include. Consraints can be examplified with budget, and the criteria can be examplified with the design producing energy.*

As one last point for teachers in this group, overall they had many missing steps in their engineering design process steps descriptions, even for the ones who had a few correct steps. Example descriptions of the engineering design process steps for Question 2 and Question 3 were illustrated by the following responses:

> *"the goal of the engineering design process is bringing about a new product. The steps of the engineering design process are hyphothesizing, identification of the problem, finding to steps to solve the problem, and designing the product..*

> *"The steps of the engineering design process are, identification of the problem, bringing alternative solutions, and trying the feasibility of solutions*

Intermediate level teachers

The written responses of this group for the second task revealed that most of them have an understanding of the first two steps of the engineering design process (n = 6); identification of the problem and providing multiple solutions. In addition, five of the teachers included 'conducting research' as one of the steps of their engineering design process descriptions which was correct. Differentiating from the lower level of teachers, this group seemed not to include any irrelevant strategies in their engineering design process steps descriptions. Again most teachers (n = 7) were found to include incorrect steps but the difference was that these steps were not irrelevant to the engineering design process. Some of the phrases teachers mistakenly used were interdisciplinary approach to problems, and production. Although these were included incorrectly in the engineering design process, they were not irrelevant but related to the engineering design process. For the teachers in this group, it was recognized that there was an increase in the number of the steps they could correctly put in their engineering design process. However, they had many mistakes in the order of their steps.

For the engineering design concepts; criteria and constraints, two of the teachers had correct definitions for both. To continue, four of the teachers had at least one of these concepts correctly defined. For the examples they provided for these concepts, three of them could give correct examples to both and six of them provided a correct example to at least one of the concepts. Below were two examples from responses:

> *"examples to constraints budget and the criteria is lifting the load in the wind turbine design"*

> *"for the design of a product, for economical purposes or for accessibility purposes, there should be limitations. So that a need is met. The constraints can be a machine to meet the needs, and the criteria can be a product that the cost will not exceed 1 million.......*

It can be interpreted that the two teachers seemed to be successful in providing examples to criteria and constraints and they could distinguish between the two. Their examples did not include a great variety mostly limited. For the teachers in this group, it was observed that they were poor in producing alternative examples to constraints. Almost all of them had money, and/budget in their examples. Although two of the teachers could provide a variety by responding: time, labor and total energy.

Expert level teachers

For the last group of teachers on the second task, the most remarkable finding was that none of them had any irrelevant or incorrect steps in their engineering design process steps description for Question 2 and Question 3. However, they still had incomplete number of steps and there were mistakes in the order of the steps. But the wrong order depiction only appeared in three of the teachers' depictions. The steps that mostly got correctly written were identification of the problem, conducting research, presentation of multiple solutions and drawing a prototype and/or drawing a model. All these four correct steps were included in majority of teachers' descriptions (n = 6). An example teacher response for Question 2 and Question 3 were provided below respectively:

> *"the engineering design process is composed of the steps; identification of problem or the needs to meet, identification of possible solutions, drawing the design, choosing the best possible solution, creating the design, testing, revising the weak points of design, and presenting the design.*
>
> *"first the problem or the need will be identified. Then there is brainstorming based on needs and choose best solution among alternative solutions. Next there is planning and drawing/sketching. Then the weak parts are revised, and testing that can result in a new prototype. then the design is presented.*

Another important finding was that more than half of the teachers (n = 6) mentioned the goal of engineering design process as both solving a problem and addressing or meeting a need. Teachers in this group were found to have an emerging understanding of the engineering design steps presenting, marketing and making revisions.

For the definitions of the concepts for Question 5 and Question 6, four of the teachers had correct definitions to both. To continue, majority of teachers (n = 7) could give correct examples to both. It was recognized that teachers could provide a variety of examples, without being limited to budget for constraint. Many of them provided examples from the engineering design challenges, so they could address their prior experience in giving examples. Two examples from teachers' responses were given below; first for Question 5 and then for Question 6:

> *".....constraints is the limitations that I need to use in terms of materials, time, things I have available to solve the problem.....*
>
> *......constraints can be material and time. Constraints can be the performance of our wind turbine first for the light load and then fort he heavy load.*

“constraints mean the things I need to use to solve the problem. Criteria can be examplified by the turning performance of our wind turbine.

....constraints can be material, time and budget. The criteria can be the turning of the wind turbine for both the light and the heavy load....

Coding Rubric for the third task of the teacher logs

The preparation of the coding rubric and analysis of data for this task showed that, the data was too spread. This meant that, it was a little challenging to locate commonalities between teachers to summarize and present. Still, a few common points were revealed following the calculation of the frequencies. The coding rubric for the third task was presented in Table 35.

Novice level teachers

While evaluating complete engineering design processes which was elaborated on with the third task, teachers seemed to discuss paying attention to budget and creating a realistic solution, drawing a prototype, and learning from mistakes. All of these aspects were evident in evaluations of more than half of the teachers (n = 6). So teachers in this group were found to make evaluations based on a limited number of aspects of the engineering design process. Teachers could not explicitly state criteria or constraints but they could name them as factors and discussed them (n = 6). One of the teachers implicitly discussed a tradeoff strategy they implemented. Teachers were noticed to use a daily language as they evaluated design processes instead of particular terminologies of the engineering design process (n = 5).

Intermediate level teachers

There were found to be more aspects of the engineering design process teachers discussed in their teacher logs. The similar points were; providing multiple solutions, drawing prototype, identification of problem and conducting research (n = 6), learning from mistakes and testing that were located on majority of the teachers’ accounts (n = 5).

High level teachers

There were many accounts of teachers as they evaluated their own engineering design performance. The similar points were; drawing a prototype, identification of problem properly, making revisions, and mention of criteria and constraints that was a differentiating point from the lower levels. A few of the teachers (*n* =3) talked explicitly about tradeoff strategy they followed.

Table 35. *Coding Rubric for the Third Task*

Levels	Specific level description
Level4	More edp steps are discussed as evaluations are made; including revisions, criteria and constraints
Level3	Can use proper particular language as in evaluation of design processes. More edh steps are discussed as evaluations are made
Level2	Starts using proper particular language. Can evaluate complete design processes on providing multiple solutions, drawing prototype, identification of problem and conducting research, testing. Can not make any evaluations based on revisions to design.
Level 1	Use of daily language instead of particular terminologies for edp steps and concepts

Comprehensive coding rubric (see Table 36) was generated based on the data analysis of the three tasks of the teacher logs. There were three main aspects of engineering design process on this rubric: a) overall engineering design process; goals, features, and model, b) engineering design process steps, and related concepts, and finally c) evaluation of a complete engineering design process. As the three coding rubrics explained above were examined, commonalities were found between coding rubric of Task 1 and the coding rubric of Task 2. As these commonalities were examined, they were first separated then combined under the first two aspects of engineering design process; a) overall engineering design process; goals, features, and model, and b) engineering design process steps, and related concepts. The third aspect evaluation of a complete engineering design process wad directly taken from the coding rubric for Task 3 on teacher logs. The next step was to finalize the third version of the learning progression was to analyze the clinical interview data.

Table 36. *Comprehensive Coding Rubric*

	NOVICE	INTERMEDIATE	ADVANCED	MASTERY
Overall engineering design process; goals, features, and model	Edp is a problem solving process. A new product is created. Edp model includes irrelevant strategies as steps. Confusion with scientific method	Edp is a systematic process with certain steps. Many mistakes in order of steps. Edp is iterative. Edp model includes no irrelevant strategies as steps.	With systematic edp, a new product is created or an already existing product is revised. Edp model includes more than three mistakes in order of steps	Connection between real life and engineering design. Almost all edp steps are correctly order, includes one or two mistakes.
Engineering design process steps and related concepts	Understand problem identification among edp steps. No definition or example for criteria and constraints.	Understands problem identification and providing multiple solutions among edp steps. Confusion with the steps; prototype, test, evaluate, present and market. Correct definition of at least one related concept; criteria or constraints. No example can be given for them.	Correct understanding of more than two steps of edp. Confusion with test, evaluate, revise, present and market. Correct definition of criteria and constraints and give at least one example. Examples mostly limited to budget and quality.	Correct understanding of most of the edp steps. Confusion on presenting and revising. Correct definition and examples to criteria and constraints. Use examples from their own experiences
Evaluation of a complete engineering design process	Use of daily language instead of particular terminologies for edp steps and concepts	Starts using proper particular language. Can evaluate complete design processes on providing multiple solutions, drawing prototype, identification of problem and conducting research, testing. Can not make any evaluations based on revisions to design.	Can use proper particular language as in evaluation of design processes. More edp steps are discussed as evaluations are made	More edp steps are discussed as evaluations are made; including revisions, criteria and constraints

b. Clinical interviews. Clinical interview transcripts were analyzed firstly in order to refine the comprehensive coding rubric on Table 36. This refined version of the comprehensive coding rubric helped to create the third version of the learning progression on engineering design process understanding.

The analysis of clinical interview data began with multiple careful examination of the interview transcripts. These examinations were completed by critically following the comprehensive coding rubric in Table 36 as well. So Table 36 served as a codebook for analysis of clinical interviews. Some new codes emerged some of which existed on the comprehensive rubric and some of them did not. They were illustrated in Table 37. The calculations were based on number of teachers again instead of number of codes appearing.

Table 37. *List of Emerging Codes for Clinical Interview Data*

List of emerging codes
Relation of problem identification to conducting research (first two steps of edp)
Explaining criteria and constraints together or with daily language
Description of edp steps problem identification, conducting research and prototype
Group work and brainstorming
More irrelevant strategies as edp steps (e.g. material use, learn from mistakes)
Description of edp steps marketing, revision, presentation
Identification on one solution among many by considering criteria and constraints
Edp for both problem solving and meeting needs
Iteration in two senses; having more than one cycle and revising various steps
Edp model as linear or cyclical
Real life examples to edp problems
Differentiation/confusion between science-engineering-edp-scientific method
Use daily language

Following the identification of the emerging codes presented in Table 35, the clinical interview transcripts were scanned several times. An experienced researcher in examination of qualitative data and engineering design process helped the researcher to code the data and reach a final comprehensive coding rubric. According to the results, majority of the teachers (n = 6) understood the goal of engineering design process as to both solve problems and meet needs.

When it comes to the critical concepts of the engineering design process; criteria, constraints and tradeoffs, the differentiations between teachers can be reported as the following. Some of the teachers (n = 4) could exemplify these concepts correctly. One of the teachers explained the relation of criteria and constraints; thus tradeoffs very well.:

> *".....it depends on the problem and the process. At one point a criteria can be a constraints and vice versa. For example if we have limited budget and we need to be careful then, money is a constraint. However if we have unlimited money then it is not a constraint any more. We decide what is most critical for us and seek for a balance between criteria and constraints……"*

As in the comprehensive rubric of teacher logs, some teachers could not define or provide any examples to criteria and constraints, whereas some of them could do both, or succeeded partially. A different finding then the teacher logs was the implicit emphasis on these concepts, which might be called educated guess of use of daily language. For example, one of the teachers was very successful in discussing tradeoff strategy with a daily life example. However, he could not talk about this strategy in relation to the engineering design process. He gave the following example, which was considered

As the case for teacher logs, teachers mostly talked about budget as en example to constraints however they also discussed time frequently (n = 6). Teachers could provide a variety examples for criteria and constraints; being friendly to nature, human labor (number of people in the team), and durableness.

> *"…the rock we throw should be worth the duck we scare…we can sacrifice from some things whereas not the others…*

When the engineering design models of teachers were examined, a similar finding with the teacher logs were found. For some teachers (*n* = 3), the design process was drawn with all correct steps, for some they included irrelevant strategies (*n* = 4), and for some there were no irrelevant steps, but the design process was incomplete (*n* = 3). Some of the irrelevant strategies that teachers put in their engineering design process model as if they were steps included learning from mistakes, trial and error, feedback and selection of materials. Especially the last one, selection of materials was found in three of the teachers' engineering design process model.

For explanation of the engineering design process steps, similar to teacher logs, some teachers could explain multiple steps correctly. Some could provide very different examples for each step, in addition to describing the role of the step. The steps that were explained by almost all teachers (*n* = 8) were problem identification, conducting research, and making a prototype. Teachers were found to have confusions explaining the steps; evaluate, make revisions, present and market (*n* = 5). These steps were found challenging to discuss in both the teacher logs and clinical interviews.

Teachers seemed clear about the iterative nature of the engineering design process (*n* = 7). As a striking finding, they could also talk about this iterative nature in two different aspects (*n* = 5). One aspect was about the cyclical nature of the process in general and the second aspect was about revising different steps of the engineering design process as needed. The second aspect that was mentioned by five of the teachers was that whenever needed, one could revisit several steps. One of the teachers explained:

> *"….after I test the product, I an go back to some of the steps, for example I can go back to the several solutions I had created and go over them……this is different than going back to the first step; problem solving following the revisions....*

Teachers reflected the iterative nature of the design process on their models as well. There were teachers who drew a linear model of the engineering design process (n = 3).

Another point of interest was about the relationship between engineering and real life. This was reflected in six of the teachers' transcripts. Some aspects of this relationship was expressed as use of knowledge from other disciplines especially science and math, awareness of an audience and end users, contribution of the engineering design process to the improvement of the society.

Confusion between scientific method and the engineering design process was evident in five of the teachers' accounts. One teacher put the steps; analysis, synthesis and construction of hypothesis in her model and she used these as she explained the engineering design process

> *"….first in the analysis step. I go over and examine my materials. Then I make some synthesis to understand what my mistake is…*

As teachers evaluated complete design processes in they mostly talked about the engineering design process steps; identification of problem (n = 5), conducting research (n = 6), drawing a prototype (n = 5) and finally making revisions (n = 5). Teachers were not successful in making evaluations based on how certain criteria and constrains were considered and tradeoff strategy was applied.

As result of these multiple scanning, coding, and discussions with the external researcher, a final comprehensive coding rubric was generated that was provided in Table 38. To sum up, the clinical interview data was analyzed that resulted in a revised version of the comprehensive coding rubric. Later this final comprehensive rubric was compared with the second version of the learning progression that was presented in

Table 32. There points that confirmed each other, and also points that included variation. Because the learning progression with levels depicted mainly the participant teachers of the teacher PD program, and also for validation purposes, the results achieved with analysis of teacher logs and clinical interviews was given priority. Still the second version of the learning progression was critically important in that it both guided the preparation of the teacher PD program content and also the overall skeleton of the learning progression.

This third version of the learning progression that was created with attention to the second version and the comprehensive rubric (see Table 38) can be examined in Table 39. This third version of the learning progression differentiated from the second version mainly in the following aspects. Firstly, the third version included three aspects of the engineering design process. Because the data revealed that the sophistication in the understanding of engineering design process should cover multiple aspects. So a learning progression with three aspects was generated which were: a) overall engineering design process, goals, features, and model, b) engineering design process steps and related concepts, and c) evaluation of a complete engineering design process. These aspects can be referred to as “trends of progress” (Jin et al., 2013, p. 1676) where each were described by using d data and presentation of ideas. Each trend of progress included four levels. This detailed version of the learning progression helped to better demonstrate the movement from a novice understanding of engineering design to a mastery level understanding (Jin et al., 2013; Mohan et al., 2009).

Table 38. *Final Version of Comprehensive Coding Rubric*

	NOVICE	INTERMEDIATE	ADVANCED	MASTERY
Overall engineering design process; goals, features, and model	Edp is a problem solving process. A new product is created. Edp model includes irrelevant strategies as steps. Confusion with scientific method	Edp is a systematic process with certain steps. The goal is to both solve problems and meet needs. Many mistakes in order of steps. Edp is iterative. Edp model includes no irrelevant strategies as steps.	With systematic edp, a new product is created or an already existing product is revised. Iterative nature includes both a cyclical process and revisiting of steps as needed. Edp model includes more than three mistakes in order of steps	Connection between real life and engineering design through engineering indicators (e.g. awareness of end users, contribution to society, and use knowledge of other disciplines). Almost all edp steps are correctly ordered, includes one or two mistakes.
Engineering design process steps and related concepts	Understand problem identification among edp steps. No definition or example for criteria and constraints.	Understands problem identification and providing multiple solutions among edp steps. Confusion with the steps; prototype, test, evaluate, present and market. Correct definition of at least one related concept; criteria or constraints. No example can be given for them.	Correct understanding of more than two steps of edp. Confusion with test, evaluate, present and market. Correct definition of criteria and constraints and give at least one example. Examples mostly limited to budget, time and quality. Implicitly discuss tradeoffs	Correct understanding of most of the edp steps. Confusion on presenting and revising. Correct definition and examples to criteria and constraints. Use examples from their own experiences Discuss tradeoffs in selection of one solution.
Evaluation of a complete engineering design process	Use of daily language instead of particular terminologies for edp steps and concepts. Evaluate weaknesses wihout referring to edp steps necessarily.	Starts using proper particular language. Can evaluate complete design processes on identification of problem, conducting research, testing. Can not make any evaluations based on revisions to design.	Can use proper particular language as in evaluation of design processes. More edp steps are discussed as evaluations include referring to providing multiple solutions, drawing prototype, and making revisions are also discusses.	More edp steps are discussed as evaluations are made; including revisions, how criteria and constraints were considered.

Table 39. *Third Version of the LP on Engineering Design*

	NOVICE	INTERMEDIATE	ADVANCED	MASTERY
Overall engineering design process; goals, features, and model	Edp is a problem solving process. A new product is created. Edp model includes irrelevant strategies as steps; mostly learning from mistakes and choosing materials. Confusion with scientific method	Edp is a systematic & iterative process with certain steps. The goal is to both solve problems and meet needs. Many mistakes in order of steps. Edp model includes no irrelevant strategies as steps.	With systematic edp, a new product is created or an already existing product is revised. Iterative nature includes both a cyclical process and revisiting of steps as needed. Edp model includes up to three mistakes in order of steps	Connection between real life and engineering design through engineering indicators (e.g. awareness of end users, contribution to society, and use knowledge of other disciplines). Almost all edp steps are correctly ordered, includes one or two mistakes.
Engineering design process steps and related concepts	Understand problem identification and conducting research among edp steps. No definition or example for criteria and constraints.	Understands problem identification and providing multiple solutions among edp steps. Confusion with the steps; prototype, test, evaluate, present and market. Correct definition of at least one related concept; criteria or constraints. No example can be given for them.	Correct understanding of more than three steps of edp. Confusion with test, evaluate, present and market. Correct definition of criteria and constraints and give at least one example. Examples mostly limited to budget, time and quality. Implicitly discuss tradeoffs	Correct understanding of most of the edp steps. Confusions with evaluating, presenting (communicating results), and marketing Correct definition and examples to criteria and constraints. Use examples from their own experiences. Examples not limited to budget, time and quality. Discuss tradeoffs in selection of one solution.
Evaluation of a complete engineering design process	Use of daily language instead of particular terminologies for edp steps and concepts. Evaluate weaknesses without referring to edp steps necessarily.	Starts using proper particular language. Can evaluate complete design processes on identification of problem, conducting research, testing. Can not make any evaluations based on revisions to design.	Can use proper particular language effectively in evaluation of design processes. More edp steps are discussed as evaluations include referring to providing multiple solutions, drawing prototype, and making revisions are also discusses.	More edp steps are discussed as evaluations also include; making revisions, how criteria and constraints were considered. Can discuss application of tradeoff strategy.

Another point was that in the second version, it was expected that teachers at higher levels would understand and discuss different models of the engineering design process model as they were elaborated on in the PD program as well. However, teachers could not express ideas on different models, their similarities and differences. For the third version, this part was removed. To continue, in the second version, the fact that teachers could also differentiate on whether they can make connections with real life and engineering design/engineering practices was not focused on. However, as data was examined, it was revealed that as teachers got more sophisticated in their understanding, they could make such connections. These connections were reflected as awareness of end users, contribution to society, and use knowledge of other disciplines in the learning progression.

About engineering design process related concepts, in the third version, it was revealed that as understanding gets more sophisticated, teachers start describing criteria, and constraints with their own design process examples, in addition to listing examples for both. Again the third version demonstrated that teachers can exemplify these concepts using the same examples; money (e.g. budget) mostly. However, as teachers increased in levels, they start to mention a variety, such as being friendly to nature, and durableness.

Chapter 4; Results presented the findings of the study under two main sections: a) development of a learning progression and survey on teacher attitudes, and b) development of a learning progression on teacher understanding of the engineering design process. Under each section, findings leading towards the first, second, and third versions of the two learning progressions were presented. Each section included separate data analysis results that were in line with the methodology framework of the study presented in Table 4. The results of the data analysis included literature search, written assessments, cognitive interviews, item paneling, survey on teacher attitudes, teacher logs and finally clinical interviews.

CHAPTER 5

DISCUSSION

The conclusions and recommendations based on the results of the study were reported in two sections; a) the teacher learning progression and its associated survey on teacher attitudes, b) the teacher learning progression on teachers' understanding of the engineering design process, both in relation to the teacher PD program implemented at the Phase 2 of the methodology framework (see Figure 8). These two sections reflected the two research questions of the study aiming towards developing the two learning progressions.

5.1. Teacher Learning Progression and Survey on Attitudes

For the development of the first version of the learning progression, a literature search, and data collection with written assessments were completed. The second version of the learning progression and the survey on teacher attitudes were put forth following both an item paneling and data collection with cognitive interviews. This was followed by the delivery of a teacher PD program. The third version of the learning progression on teacher attitudes (see Table 26) was created with the analysis of the data collected with the survey; "Science Teachers' Attitudes towards K-12 Engineering Education Survey". The development of an associated survey with the learning progression was critical since the assessment items aligned with the learning progressions can show the place of the respondents along a continuum. The overall findings were discussed in light of the literature.

The learning progression was constructed to have five levels, ranging from highly negative attitude to highly positive attitude. Likewise, the survey items had a response scale to have a variance in options and in attitude levels; ranging from strongly disagree (1) to strongly agree (5). Data analysis was completed based on Rash analysis following the Partial Credit Model (Zheng, 2016). The results revealed information on the reliability and validity estimates, item difficulties and misfit items. The most essential finding was concerned with the empirical alignment between the survey items and the levels of the learning progression from the lowest level; resistant to the highest level; advocate. It was revealed that the spectrum of the items; the item difficulty was not sufficient enough to cover for the teachers; the variety in teachers' endorsement levels. The insufficiency in this alignment can be exemplified over an achievement test where there were so many easy questions and respondents accumulated at the top level. Results showed an accumulation on the top levels.

The results were different than the surveys developed by Mahat (2008) and Nguyen and Griffin (2012) in covering the attitudes where the authors also construct modeling measurement framework. In these studies, the respondents showed a normal distribution where they accumulated in the middle levels of the learning progression. However, in the current study the items did not cover teacher attitudes properly. Teachers were high above the items which addressed the fact that it was easy for teachers to agree with the majority of the items. A point of attention was that the two studies mentioned above did not work on attitudes towards a new approach or a perspective such as engineering in education (MoNE, 2017; NGSS Lead States, 2013; NRC, 2012) rather they worked on attitudes towards an object already common to the participants were measured. So it might be the case that, in these two studies, the respondents had varying degrees of experience on the subject which resulted in a variety in their responses. However, for the current study, the subject of attitude; engineering education and integration of engineering is new and exciting to teachers. Although teaches were selected to the PD program based on different experiences on engineering, still even the most experienced teacher can be considered novice, because engineering practices is still very recent in especially the Turkish context

(MoNE, 2016). The new draft middle school science curriculum introduced by the Ministry of Education in early 2017 (MoNE, 2017), covered a on engineering concepts and engineering design principles from grade level four to grade level eight. When it comes to the successful classroom implementation of engineering practices it is influenced by characteristics of STEM teachers as well (Çorlu et al., 2014). Taking these points into consideration, teachers not having much experience with engineering might have caused a surface level of thinking on the items, where most items seemed appealing and they could not reflect their true attitudes because they did not have much experience in real classroom environment.

To reach a successful distribution and a variety in respondents' scores and thus a strong empirical alignment between the learning progression and the items is critical in two senses. Firstly, the empirical alignment between the survey items and the learning progression is an evidence for construct validity of the learning progression (Wilson, 2005). Second of all, it signifies that the survey does not appeal to or is not informative of the teachers who have highly positive attitudes which will limit its future use. In the current study, it might be the case that teachers have approached the items mostly positively integration of engineering appealed to them as a very recent initiative. PD programs are influential in shaping teachers' attitudes towards positive attitudes on new pedagogies; inclusion (Male, 2011), technology integration (Overbough et al., 2015), inquiry-based science education (Kapanadze et al., 2015). Because, teachers don't have any experience with engineering in terms of implementing in class, maybe every aspect of engineering sounded attracting to them. It is also noteworthy that it is a challenging process to change attitudes which takes time (Grossman, Onkol, & Sands, 2007). Maybe if the same teachers are followed-up in time, as they implement engineering design activities in their classes, they may give different responses to the items. Table 2 presented that many of the teacher PD programs on K-12 engineering preferred to include a follow-up where teachers implement engineering activities in their classes. This way, teacher PD programs were extended beyond the face-to-face workshop (Nadelson et al., 2015). Teachers can practice integrating engineering in such follow-ups (Cunningham et al., 2007) and after that, data on their attitudes can be collected again. Implementation of an instrument on attitudes right after the teacher PD program might have caused the

teachers to tend to agree with majority of the items. Such follow-ups can help teachers not only learning engineering but also implementing it successfully in their classes (Hynes & Santos, 2007). The follow-up can include teachers' implementing engineering activities in their classrooms and receiving feedback on their implementations. A follow-up might enable teachers to experience implementing engineering in a real classroom context with their students. Teachers might need to become involved in their beliefs and attitudes to be shaped. Changes in teachers' behavior is effective in shaping teachers' attitudes (Hew & Cheung, 2014).

Another point of attention supported the above reached conclusions about the effect of teachers not having sufficient experience on engineering to reflect their true attitudes. It was observed that when teacher responses collected before their participation to the teacher PD program was statistically examined, teachers were better represented by the item set. However, the responses both collected before and after the PD program was statistically examined, the representation of the items was less sufficient. It might be inferred that teachers' attitudes increased positively with participating to the teacher PD program since PD programs are effective in changing attitudes (Davidson, Jensen, Klieme, Vieluf, & Baler, 2009). The role of teacher PD programs in influencing attitudes positively was evidenced in the literature (Al Salami et al., 2015; Martin et al., 2015; Yoon et al., 2013). Another point related to the PD program might have been that the presentation of the engineering design activities seemed too idealistic. If discussions have taken place during the teacher PD on the implementation of the engineering design activities in class where teachers could reflect on their genuine experience with engineering. The challenges that teachers face in real learning and teaching environments are related to their attitudes (Chung et al., 2015). Even though the PD program presented teachers with opportunities to learn about engineering practices, it might be the case that this experience directly resulted in highly positive attitudes in the case of the survey used to collect data. Maybe the teachers could not find the time to reflect on what they had learnt in the PD program yet. So again, the survey can be administered once again in near future where teachers probably implemented some engineering activities in their classes; gained experience, and had time to think about that they learnt.

It is important to clarify that the goal was not to avoid teachers with highly positive attitudes. Because the goal of the study was to develop a learning progression with its associated instrument, for validation purposes, the alignment between the learning progression and the survey was critical. In light of the results of the study, it was revealed that teachers were not distributed well to levels which signified a poor alignment. This meant that the items were very easy to agree with; the survey lacked items that were harder to agree for teachers which would place them into lower levels of the learning progression as well. When the studies who were successful in capturing a high-quality empirical alignment between their learning progression and its associated instrument were examined (e.g. Alonzo & Steedle, 2009; Jin et al., 2015; Wang et al., 2015) important conclusions can be reached. First the instruments associated with the learning progression included items that captured the ability level of respondents; which is attitude for the current study. Therefore, the items ranging from easy to agree to harder to agree is critical rather than having a majority of easy to agree items. This was one of the conclusions reached for the current study. Teachers especially could not be separated sufficiently, in other words items that were not successful in distinguishing between attitude levels were on interest and motivation to learn about engineering practices and integration of engineering, and contribution of engineering to development of students and improvement of society. The future version of the survey needs a careful consideration in having harder to agree items on these aspects in particular. Example studies on learning progressions either used large sample sizes (Duncan et al., 2016; Todd & Kenyon, 2015) or conducted more than one cycle of data collection and analysis. The current study employed one cycle of research that consisted of three phases (see Figure 7). The results of the current study showing a poor distribution of teachers might be influenced by sample size and that only a single Rasch analysis was conducted.

When the framework for analysis of teacher practices and beliefs (Davidson et al., 2009) was examined which included teacher attitudes as well, it was noticed that teacher attitudes are first formed in consideration to teacher background; prior education and experiences. Later, the newly emerging beliefs, and attitudes are shaped in relation to student background, teacher background, classroom-level environment, and school-level environment. Teachers' professional activities such as participation to professional trainings and experiences are also critical at this point. Later as teachers observe effect on student learning and on other student outcomes, their overall beliefs and attitudes are shaped. This point was elaborated in the attitude change model by Kelman (1958) that included three stages to explain the change in attitudes; 1) compliance, 2) identification, and 3) internalization. For for the current study, it can first be concluded that teachers had an emerging belief and attitude towards engineering before participating to the PD program. With the teacher PD program, they had chance to shape their attitudes with the things they learnt. Currently, in line with the two models exemplified, teachers might benefit from observing the effectiveness of engineering for their students, and they need to see what they learning in the PD program in relation to their school and classroom environment. Therefore, the administration of the survey following the PD program might present useful results, however in order to get a better picture of teachers' attitudes, their having experiences with engineering in their school context is critically important. As de Souza Barros and Elia (1997) illustrated in their teacher attitude model, although pre-service teacher programs and PD programs have a role in shaping teachers' attitudes, teacher competencies, together with the school and society are also vital.

In particular, items on implementation or teaching of engineering were relatively more successful in creating a variety in responses and thus increasing the validity of the learning progression. These findings pointed to the fact that different aspects of teacher attitudes related to actual classroom teaching and implementation can be highlighted more in the survey items. In line with these findings new items were added to the final version of the survey on attitudes that included enjoyment in teaching (Lachapelle et al., 2014), attitudes towards teaching (Van Aalderen-Smeets & Van Der Molen, 2013; Yu et al., 2012), and outcome expectancy (Hart & Laher, 2015) since teachers' expectancy of performance can also be an important component of attitudes (Ifenthaler & Schweinbenz, 2013). Other aspects that can be elaborated on might include teacher confidence (Hynes & Santos, 2007; Klein, 2009), and teacher comfort (Cunningham et al., 2007; Diefes-Dux, 2015). According to Rink and Stewart (2003), teachers who believe in their level of teaching are confident about it are more ready to implement new things. The items could include points on perceived usefulness of engineering referring specifically to its teaching methods, how it can exist with other current instructional methods (Hart & Laher, 2015), and when to teach engineering (Lachapelle et al., 2014).

Teachers' attitudes can also be reflected in their comfort in teaching engineering in order to have a better distribution of responses. Teachers' level of comfort in might be an important distinguisher that can be included in investigation of teachers, attitudes towards K-12 engineering education. Confidence about teaching a subject content (McCullouch, 2016) is another aspect of teacher attitudes that might make the respondent teachers think harder on the item and thus make the item more difficult to agree with. When teachers have experience on basic engineering principles and methods, they can increase self-confidence on teaching engineering concepts and engineering design process (Goodale, 2013). Teacher attitudes might include teacher perceptions (Baker et al., 2007; Iskander et al., 2010; Poole et al., 2001), and teacher satisfaction (Yoon et al., 2013) as well. To sum up, inclusion of these different aspects of teacher attitudes that can be referred to as job-related attitudes such as self-efficacy; teachers' beliefs regarding their effectiveness (Davidson et al., 2009) to the learning progression and the survey items can help to increase their quality and validity. Such aspects were highlighted in other teacher attitude surveys; attitudes towards teaching

(Yu et al., 2012), familiarity with teaching (Yaşar et al., 2006), motivation towards preparing and implementing engineering practices in class, and enjoyment in teaching engineering (Faber et al., 2013; Nadelson et al., 2013). Exposure to the work of engineers is an influential factor in shifting teachers' perspectives and attitudes positively towards and engineering and also STEM (Nadelson et al., 2013). The PD program that teachers participated in included engineers who took part in; a) a panel where they discussed their discipline and the work they do, b) an introductory presentation on nature of engineering, and the work of engineers, and c) giving feedback on the design process and on final designs. These three parts were included in the program due to the benefits collaborating with engineers for teachers (Moskal et al., 2007; Nugent et al., 2010, Winn et al., 2009). This collaboration might have a role in explaining teachers high level of positive attitudes. Therefore, it might be a better idea either to use the same survey in a PD where work of engineers is not that emphasized, or modify the items and test them again

The development and validation of the teacher learning progression on attitudes followed the construct modeling measurement framework (Wilson, 2005) to analyze data and reveal the empirical alignment between the learning progression levels and the items in the survey. Although the development and and validation procedures of learning progressions include variety, following the construct modeling framework presented a systematic approach. Developing an associated instrument with the learning progression; that is aligned with the levels of the learning progression and later conducting Rasch analysis (Lee & Liu, 2010; van Rijn et al., 2014) are critical ways of validating the learning progressions (Alonzo & Steedle, 2009; Nguyen & Griffin, 2012). The current study employed the two strategies which is important for validity and reliability purposes. However, using the PD program as a context in addition to the two validation methods might have not contributed much to the results. Future studies might test the learning progression and the survey on teachers not necessarily participating to the teacher PD program.

The structure of the learning progression was more comprehensive compared to other developed learning progressions which were called as construct maps on attitudes (Mahat, 2008; Nguyen & Griffin, 2012). In these learning progressions on attitudes, the levels did not include any explanation regarding teachers' attitudes belonging to that level. Instead, the construct map only was shown with decreasing and increasing arrows depicting an increase and decrease in attitudes. In that sense, especially with the third version of the learning progression, an alternative demonstration to learning progressions on attitudes was proposed which made level descriptions clear. This made the levels similar to learning progressions developed on variables other than attitude such as understanding of biodiversity (Songer et al., 2009) and mapping chemistry understanding (Claesgens, Scalise, Wilson, & Stacy, 2009) that included detail in level characteristics.

In the third version of the learning progression on attitudes, with regard to all issues discussed, the refinements made to generate the third version of the learning progression can be summarized as; a) keeping the number of levels to three for the aspects; interest and motivation to learn about engineering practices and integration of engineering, and contribution of engineering to development of students and improvement of society, and b) keeping the number of levels at five for interest and motivation to improve oneself professionally and motivation towards preparing and implementing engineering practices in class. The refinements to create the final version of the survey were listed as In line with the results of the data analysis and the third version of the learning progression, the refinements to the survey to create its final version were: a) deletion of the unsuccessfully performing items, b) refinements in the outcome space; scoring of items, c) addition of more items on aspects of teacher attitudes that reflected teaching, and on teachers' professional development and d) addition of Guttman type items

5.2.Teacher Learning Progression on Engineering Design Understanding

For the refinement and validation of the teacher learning progression on understanding of the engineering design process, implementation of a teacher PD program (Jin et al., 2013; Songer et al., 2009), and collection of empirical evidence from the participants of the teacher PD program (Jin et al., 2013; Mohan et al., 2009) were leading. The third version of the learning progression on teacher understanding (see Table 39) was generated with the analysis of data collected with teacher logs and clinical interviews. The first and second versions of the learning progression were created with data collection and analysis of literature search, written assessments, and item paneling.

To begin with, the development and validation of the learning progression was considered explanatory as was the case for Breslyn et al. (2016). This meant that the current study did not develop an instrument associated with the learning progression levels and a large sample size was not included. The efforts were towards laying out what understanding of the engineering design process from novice to more sophisticated might look like; which was similar to a pilot study. Similarly, the study by Claesgens et al. (2009) used open-ended questions to map students along a continuum of chemistry understanding. Their learning progressions included five levels and with the scoring rubric they prepared, students responses to the open-ended questions could be scored accordingly and placed to levels. The further validation of the levels can be completed with larger samples sizes or with new delivery of the PD program to other teachers so that the levels are validated.

When the third version of the learning progression was compared with its first and second versions, critical findings were revealed. The main refinement in the learning progression was that it was revised to include three aspects, or "trends of progress" (Jin et al., 2013, p. 1676) of the engineering design process. These were: a) overall engineering design process, goals, features, and model, b) engineering design process steps and related concepts, and c) evaluation of a complete engineering design process. The learning progression proposed four levels which were novice, intermediate, advanced, and mastery level of understanding. The novice level represented the lower level or the lower anchor of the learning progression. The mastery level represented the highest level of understanding which can also be referred to as the upper anchor. For each of the three aspects, how understanding could evolve from novice to more sophisticated was documented based on both the existing literature and empirical data collected and analyzed throughout the study. There are similar learning progressions on understanding that presented more than one progress variable, or aspect such as; Claesgens et al. (2009), Hadenfelth et al. (2016), and Jin et al. (2012). Due to the comprehensiveness of the core idea selected which is engineering design process for the current study, benefiting from more than one aspect emerged as a need as data was collected and analyzed.

In the development of the upper anchor, mainly the existing research studies and standard documents describing the process and characteristics of the engineering design were influential (Berland et al., 2014; Cunningham, 2009; Massachusetts Department of Education, 2006; Moore et al., 2014b; NRC, 2012) as typical of learning progression studies. The overall commonalities among these sources were reflected in the highest level of the first and second versions of the learning progression. Accordingly, it was assumed that teachers at the highest or the mastery level could understand all engineering design process steps; define problem, research the problem, develop possible solutions, select the best possible solution, construct a prototype, test, redesign (revising), and marketing. However according to the third version of the learning progression even for the teachers that were superior in terms of the understanding, not all design steps could be properly understood. The steps that were easier to understand by the teachers were problem identification, conducting research, and making prototype. However, teachers were found to have more difficulties explaining the steps; testing, redesigning (revising), presenting (communicating results), and marketing. The PD program might be examined in terms of to what extent each design step is elaborated on. It seemed that some design steps might have been given more focus.

It was confirmed that understanding of the the steps; (share) results, and marketing were relatively more difficult to understand. Among the particular studies which were also effective in creation of the second version Hsu et al. (2010) reported that the two steps; improve and document were more challenging to comprehend whereas the steps; test and revise were relatively easier. These findings were consistent with the third version of the learning progression. When these findings were combined in relation to the teacher PD program, some highlights can be observed. For the steps that were relatively more difficult for the teachers to understand and describe; presenting, documenting, presenting (communicating results), and marketing, teachers actually presented their final designs to the big group and therefore communicated their results. However, a discussion did not take place on how to improve the results based on feedback from the group. Teachers did receive this kind of feedback from engineers and trainers when they visited each design team at their working place. Maybe teachers were not aware if the fact that they were communicating results. They might have just perceived the situation as selection of the best design. So maybe if each team's final designs were better communicated with more elaboration on weaknesses and strengths, they could better comprehend the engineering design step; presenting (communicating results). The future PD program can benefit from a short report written by the design teams on their engineering design process and on their final designs. To continue, the engineering design model by Massachusetts Department of Education (2006) could have been given more focus. The more focus on engineering design process model by Cunningham (2009) could have caused teachers' not being able to understand the steps that required more information and proficiency.

The order of the steps was not a focus in the second version of the learning progression. Again for the third version, such a point was considered with the tasks in data collection tools in order to better document teachers' understanding. The results showed that as teachers' understanding gets more sophisticated, they tend to make less mistakes in the order of the engineering design process steps. Information on the order of the steps were provided in both presentations in the PD program; one on the first day and one on the second day. Additionally, with the documents teachers used as they worked on their designs (see Appendix G), they followed the engineering design steps in the correct order. This documents might have been helpful for teachers to learn the correct order of steps. As teachers reach the mastery level of understanding, their engineering design process models only included one or two mistakes.

Table 1 presented in Chapter 2; Review of Literature, can be compared with the results of the study that was based on Moore et al. (2014b) and NRC (2012). This table was useful in comparing the previous versions of the learning progression to its third version. With the second version of the learning progression, it was expected that teachers could understand that the engineering design process is iterative at the higher levels of the learning progression. The nature of the process being iterative was documented in many of the existing studies reviewed (Berland et al., 2014; Cunningham, 2009). However, the third version put forth that even teachers at the lower levels of the learning progression can explain the iterative nature of the process. There was a major point that as teachers get to more advanced levels of the learning progression, they start to think of the iterations in two aspects. So they can explain not only the the engineering design cycle repeating itself in cycles, but also that the process is flexible and one can revisit different steps as needed. Engineering design depends on iteration which is making various refinement during a design process (NRC, 2009). Teachers' showing improvement in understanding this critical concept was important which resulted in another refinement towards the third version. This finding can be explained again with the teacher PD program. First of all, the presentations on engineering design process and the engineering design challenges including the refinement of the designs following feedback from the engineers and the trainers might have caused all participants understand the iterative nature of the process. This was in line with the previous findings that teachers could understand the engineering design step; making revisions (improving) before they reach higher levels. So the PD program activities pushing teachers to go back and refine their designs seemed effective in teaching them about the possible iterations which meant going back to the beginning of the engineering design process. For the second aspect; revisiting different steps was only particularly addressed during the presentation given at the beginning of the second day. Still in addition to this presentation, there was a discussion in the question and answer session afterward. It was the case that this discussion took around 15 minutes and teachers reflected on whether it is possible to be flexible about the steps. Some of the teachers asked questions about the possibility of changing the place of some steps and also about whether it is possible to first conduct research and then identify the problem. This discussion that almost all teachers actively engaged in could have sparked the high level understanding about the iterative nature of the engineering design process. Also this discussion could have played a role in the fact that understanding of the first two steps of the engineering design process; identification of the problem and conducting research were at the lower levels of the learning progression. So teachers found these beginning steps relatively easier to remember, put on their models and explain. In the refined version of the teacher PD program, more discussions can take place that focus on all steps of the engineering design process and also the iterative nature from both aspects, not only the cyclical format of the model.

To continue, in the second version of the learning progression, the expectation was that teachers could be confused about the distinction between the engineering design process and the scientific model. This was again confirmed with the third version of the learning progression since teacher at the lower levels had difficulties in clearly separating the engineering design process steps from the strategies used in the scientific method. Some of the confusion points or teachers were analysis of results, experimenting, and identifying hypothesis. There were no confusions left as teachers' understanding gets more sophisticated in their understanding. This situation might have been caused by the fact that the teacher PD program did not put much emphasis on the distinctions between scientific and engineering practices (Bybee, 2011). Such differentiations must be explained since the connection on scientific inquiry and engineering design processes can result ineffective learning opportunities (Jones, 2013).

However, in future refinements, inclusion of small exercises of the engineering design process can be the case. Also as can be seen in Appendix G, the documents used by the teachers at the PD program mostly highlighted the steps of the engineering design process by Massachusetts Department of Education (2006) as well as Cunningham (2009). During future PD programs, these documents might be refined to include more than one engineering design process model. To continue, the second version of the learning progression assumed that even at the lower levels teachers can express the engineering design process both as a problem solving process and a process to meet the needs. This was confirmed however, it was concluded with the third version that, the teachers at the lowest level can understand that engineering design process is a problem solving process. Whereas the teachers at the second level can understand both aspects, problem solving and meeting the needs.

In the second version making a connection between the real life and engineering design process, or engineering practices was not a focus. This was a point highlighted in some of the sources examined in particular (NGSS Lead States, 2013). However as common trends in the examined sources were reflected, this was not put in any of the levels. With the refinements towards the third version, it was revealed that teachers at the highest level can make such connections easily. The example connections can be made by the high levels teachers were revealed as awareness of end users of the products produced with the engineering design process, contribution of the engineering design process to the society in terms of solving problems and meeting needs, and using knowledge from various disciplines as one is engaged in the engineering design process. As presented in Figure 2, the core elements influential in designing the teacher PD program included engineering design activities with real-world context (Guzey et al., 2014; Martin et al., 2015; Poole et al., 2001). This might have been an important factor in teachers' being able to make such connections.

The engineering design process related concepts, in particular; criteria, constraints, and trade-off were highlighted in both the second and third version of the learning progression. However, for the second version, it was challenging to imagine the progress in teachers' understanding of these concepts. In other words, defining the middle levels; the messy middles (Gotwals & Songer, 2013) was difficult. So the third version was helpful in that sense in positioning the levels. It was revealed that a more sophisticated understanding included defining the concepts and producing examples to them. The higher levels also highlight giving examples to the concepts based on one's own design experience. To continue, teachers can understand that consideration of criteria and constraints, and application of tradeoff strategy is critical for selecting the best solution among the possible solutions brainstormed as they reach higher levels. Judging the relevant importance of criteria and constraints and making a judgment means engage in trade-off strategy (Moore et al., 2014b; NRC, 2012) which leads to the best solution. As a last point for the highest level again, teachers can produce a variety of examples for criteria and constraints such as durability, and being environmental friendly. However, at the lower level, teachers were limited with a few examples only; budget, money and time. This can be explained with the teacher PD program focus. In both design challenges in the PD program; design of a wind turbine, and design of a Lunar Buggy car, the main constraints were time and money. Each material that the teacher design teams chose to use in their designs had a price. The total budget for each design team was limited to 40 Turkish liras. Although during presentations and discussions, the trainers highlighted different examples, still it can be concluded that, the criteria and constraints of the design challenges were more effective for teachers. For the tradeoff strategy, as engineers and trainers in the PD program gave feedback on the design teams' performance, they deliberately asked questions on the tradeoff strategy the teams used. This might have bee influential in making teachers learn the strategy. It was the assumption that teachers at the lower levels would fail to understand this strategy properly. In that sense, the third version of the learning progression was in line with the second version.

To continue with messy middles, the intermediate levels which are the most challenging to create in learning progression studies, the informative literature presented formerly in Table 12 was helpful. But again in the third version, differentiations and similarities from this informative literature were observed. As an example, Duncan et al. (2011) proposed in their rubric that teachers can make evaluations and can suggest ways to improve as understanding gets more advanced. Similarly, third version showed that teachers start using an appropriate language with particular engineering design terminology and make evaluations of complete engineering designs. Secondly, Bailey and Szabo (2006) revealed that as teachers' understanding gets more advanced they can identify strengths and weaknesses of complete design processes. Another confirmatory point was that, the authors also found out that teachers can explain and show a higher level understanding of more number of engineering design process steps as they become advanced. A last example can be that similar to Baker et al. (2007), as understanding got more sophisticated teachers could see the reciprocal role of science and engineering and their role. It was also similar to their results in that, teachers start to understand the iterative nature of engineering design and see it as less formulaic as their understanding gets advanced. To sum up, the informative literature sources presented in Table 12 were useful in developing the first version of the learning progression especially for messy middles. Now with the third and last version for the current study, many confirmation points could still be found although this latest version have gone through many changes with analysis of data.

For teachers' progress on the learning progression in terms of how they can evaluate a complete an engineering design process, the second version can be considered weak in terms of differentiating levels. The only information that could be speculated was that teachers would be able to evaluate strengths and weaknesses of a design process once they reach higher levels. The third version revealed more details on this. The teachers at the lower levels were more keen on making overall evaluations without necessarily referring the the steps of the engineering design steps. However, as teachers' understanding of the engineering design process gets more sophisticated, teachers can easily address certain steps of the engineering design process as they talked about the engineering design process. Similar to the results discussed above, teachers more easily made comments about the steps, identification of problem, conducting research, and testing. These steps were the simple ones as in the engineering design process model by Cunningham (2009). It might be the case that teachers were able to learn engineering design process based on this simpler version during the PD program. Teachers' not being very successful on the later stages of the engineering design might point to the fact that teachers could not grasp the more complicated steps during PD program as shown by Massachusetts Department of Education (2006). The engineering design steps that teachers were revealed to be unsuccessful in terms of their understanding could have been more focused on with this model. Making evaluations based on consideration of criteria, constraints, and tradeoffs, multiple solutions, drawing prototype, and making revisions were typical of the higher levels (Moore et al., 2014b; NRC, 2012). The teacher PD program did not include a particular part where complete engineering design processes were evaluated by the teachers. It might be the case that as teachers learn the engineering design process steps and the concepts related to the engineering design process, they started to progress on making evaluations as well. Another influential point could be that as teacher design teams presented their final designs both for the wind turbine and the Lunar Buggy car, other teachers made comments and evaluations. In order to refine the PD program, teachers can be allowed to make evaluations on other design teams' performance on engineering design process steps as well, not only evaluate the final design.

When the basis of development for learning progressions was considered, there are studies that rely only on exiting research findings and expert opinion in developing the learning progression levels (Duncan et al., 2009; Neumann et al., 2013). However, supporting the levels empirically with data contributes a lot to the validity (Jin et al., 2013; Songer et al., 2009; Stevens et al., 2010). So there were not associated instrument developed aligned with the learning progression however, alignment with support from instructional context, curricular activates, and empirical data contributed to the validity of the learning progression. To continue with the development of learning progressions, typical learning progression development efforts make use of large sample sizes such as; 342 sixth to twelve grade students (Mayes et al., 2014), 939 students and 23 teachers (Songer & Gotwals, 2012), and 2688 students and 29 teachers (Lee & Liu, 2010). If an associated instrument is developed with OMC items, administration to such large samples can be probable. As a last point, learning progression development is an iterative process (Mohan et al., 2009). Usually learning progressions are developed with multiple cycles; piloting and then several studies (Furtak, 2009; Neuman et al., 2013; Windschitl et al., 2012). Because the initial versions need to be tested many times before it is finalized to be used with its associated instrument or an instructional context. The learning progression on teachers' understanding of the engineering design process was presented with the third and final format for the current study.

Evaluation of the learning progression. The third version of the teacher learning progression developed on engineering design process understanding was evaluated based on a systematic learning progression review framework generated by Kobrin et al. (2015, p. 62) presented in Figure 29. This evaluation resulted in strengths and in points to improve for the developed learning progression.

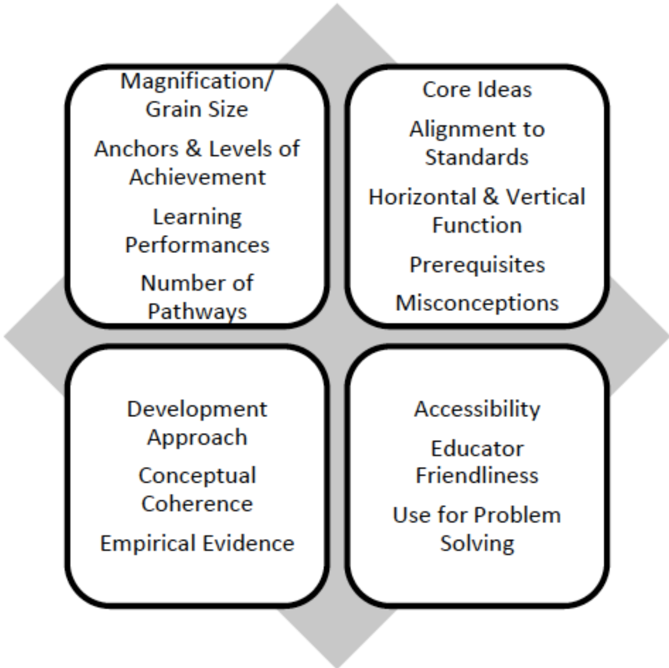


Figure 29. Learning progression review framework (Kobrin et al., 2015, p. 62)

According to this review framework, the developed learning progressions can be examined under four main categories; a) structure, b) content, c) usability, and d) validity.

The categories had sub-categories as well which were elaborated on in detail. The sub-categories can be examined in the figure under four main categories. The framework can be used in evaluating a developed learning progression with regard to the categories' existence or nonexistence. For the first category; structure, the developed learning progression was a zoomed-in learning progression instead of a zoomed-out one in terms of magnification and grain size. This meant that teachers' possible progression of sophistication in understanding happened during a short period of time, which was a two-day teacher PD program. Whereas a zoomed-out learning progression could focus on progression through a year, or across grades for the case of student progression. Still for the same category; in terms of anchors and levels of achievement, the developed learning progression systematically presented an upper anchor, a lower anchor and intermediate levels. The intermediate levels are especially critical since they can drive activity design in the future. For the third and last sub-category; learning performances, the developed learning progression failed to include information learning performances for each level, although it included the level characteristics in detail. If it also included the learning performances for each level, better interpretations can be made on teachers at a particular level.

For the next category; content, the learning progression was successful in selecting a core idea; the first sub-category which is an underlying concept and reflecting it in all levels which was engineering design process understanding. According to the framework, the core idea should be an idea that is found significant to know and to learn by experts and organizations. At this point, the developed learning progression was successful in that, integration of engineering practices and engineering design as a context to teach science was presented in the new draft middle school science curriculum in Turkey (MoNE, 2017). The relevance and significance of teachers improving themselves on engineering design practices (NRC, 2009; Yu et al., 2012) has positive effects on students as well (Li et al., 2016; Marra et al., 2000). For the next sub-category; alignment to standards, the content addressed by the learning progression should relate to a set of educational standards accepted. Again the newly proposed curriculum addressing integration of engineering (MoNE, 2017) can be an example. Engineering standards by Massachusetts Department of Education (2006) and other relevant educational reports on the issue (NGSS Lead States, 2013; NRC, 2012) can be additional supportive examples. For the next sub-category, function, the developed learning progression had a horizontal function in that it was limited to a certain time span which was a two-day PD program. For the last two sub-categories, the developed learning progression should be improved because it did not include any information on pre-requisite knowledge or misconceptions on its levels. The misconceptions teachers have, were captured during clinical interviews however the goal was only to reveal novice teacher thinking. Therefore, pre-requisite knowledge and misconceptions unique to each level might be captured in the future version to strengthen the learning progression.

For the third category; usability, the first sub-category was accessibility and educator friendliness. At this point, the learning progression's organization of levels was clearly presented to be comprehended by educators. However, any possible instructional support scenarios for levels was not created. This meant putting instructional strategies to levels so that an educator of a PD program understands what he/she should do to make a lower level teacher a higher level teacher. Although this is not existent on the learning progression currently, with future examinations, it is a necessity. Another lacking point was concrete examples used in levels. Although such concrete examples were evident in some of the levels (e.g. examples mostly limited to budget, time and quality), the learning progression needs improvement at this point. Atman, Chimka, Bursic, and Nachtmann (1999) also found out that engineering students were limited to do information search only on materials and cost. For the second sub-category, usage as a problem solving tool, the usage of the learning progression by an educator is highlighted. This educator is the designer and trainer of the teacher PD program for the current study. According to the framework, such a potential educator can use the learning progression for the following however not all are expected together; to identify misconceptions, to identify concepts that need to be retaught, to revise a curriculum or instruction, and to consider appropriateness of the instruction. Among these potential uses, the developed learning progression can be used for the last three approaches, especially when it is validated with another data cycle. This is the case due to the fact the learning progression was developed in alignment with a particular instructional context; a teacher PD program, for validation purposes. In that sense, when the presented learning progression and the PD program are finalized following future validation, they can be used in alignment easily. Thus, teachers participating to the PD program can be measured on their engineering design understanding with the learning progression which was one of the goals of the study. For the fourth and the last category; validity, the first sub-category was development approach. The developed learning progression can be considered strong at this point because it merged two of the development approaches proposed by the framework; bottom-up and top-down. To clarify, the development of the levels was based on both personal educational experiences and analysis of content domains, and expert opinions. Still the levels could benefit from the learning theory research which was not particularly focused on for the current study. For the final sub-categories, the developed learning progression had conceptual coherence and research base since it relied on informative literature findings. Lastly, the development procedure also depended on empirical evidence in the form of written assessments, clinical interviews and teacher logs. These can be noted as strengths of the developed learning progression.

To summarize the conclusions reached with the application of the framework in Figure 29, the teacher learning progression on engineering design understanding was satisfactory and successful from various aspects. There are also aspects that refinements can be made with future studies, so that all categories in the framework are addresses and applied sufficiently. This framework was not used to evaluate the teacher learning progression on attitudes because it is more suitable to use for learning progressions on understanding of a certain content, rather than a psychological construct such as attitudes. According to the overall results of the evaluation made, the teacher learning progression especially needs to be improved on the two categories; structure and usability.

5.3.Conclusion

Science and engineering learning for all students can highlight attention to innovative approaches in instruction and assessment (NGSS Lead States, 2013). In teaching science around the core ideas to learn, students should be exposed to scientific and engineering practices (NRC, 2014). Students' possession of science and engineering knowledge can enable them to consume scientific and technological knowledge carefully, and to be involved in discussions on both daily life and global issues (NRC, 2012). Its future outcomes for the students and the society necessitates attaching priority to integration of engineering practices to K-12 science education. In the Turkish context it is getting more common for K-12 students to work on problems that address the four disciplines and where they follow the engineering design process. The Technology and Design course for the 7th and 8th grades, short-term STEM activities and projects for K-12 students (Gencer, 2017; Karahan et al., 2015; Yamak et al., 2014), and in-service teacher training programs are some examples from the national context where engineering design processes is emphasized. Also with the new draft science program is examined that was shared in early 2017, integration of engineering concepts and engineering design process to science education is one of the fundamental focuses. STEM education is gaining more attention in K-12 classrooms in Turkey (Akgündüz et al., 2015; MoNE, 2016). The current study can help to contribute to these innovations in both national and international contexts.

In order to raise students who can meet the challenges of the future society, there is a connection recognized between engineering and K-12 education (NRC, 2012). In order to motivate and raise confidence in students towards careers in science and engineering, teachers should be equipped with an understanding of engineering (Jeffers et al., 2004). Goodale (2013) pointed to the fact that with the introduction of NGSS (NGSS Lead States, 2013), science teachers are expected to teach elements of engineering in their classrooms. Working on engineering design process in K-12 level education can create various opportunities for students to learn science, mathematics, and technology (Stohlmann, Moore, & Roehrig, 2012). These points addressed the need for training teachers who will be expected to teach engineering concepts and engineering design activities. Teacher preparation programs have contributed to training STEM educators in K-12 classrooms, but more attention is needed to prepare teachers for the teaching of engineering concepts (Wendt, Isbell, Fidan, & Pittman, 2015). As most teachers have no or little education or experience on engineering (Cunningham et al., 2007; Lehman et al., 2014), efforts put into training teachers on engineering is worthwhile. The findings of the study addressed a new perspective to teacher development in K-12 engineering education for both national and international contexts.

Developing learning progressions for teacher development is a recent practice which is critically important (Furtak & Heredia, 2014). Teacher development is one of the four uses of learning progressions (Kobrin et al., 2015) which was exemplified with the current study. Learning progressions can also be used for teacher development to enable teachers' use of learning progressions for their students' thinking (Furtak & Heredia, 2014). Although this is another perspective to improve teachers, the current study was interested in a teacher related variable; tracking teachers' own progress and development. The current study contributed to the newly emerging effort of learning progressions for teacher development (Furtak & Heredia, 2014; Jin et al., 2015; Mahat, 2008; Nguyen & Griffin, 2012; Schneider & Plasman, 2011; Windschitl et al., 2012). The current study contributes to the emerging teacher learning progressions by presenting examples on K-12 engineering education where there were no developed learning progressions. Especially for the national context, the study is the first example of developing learning progressions. There are only a few examples of learning progressions for teacher development (Furtak et al., 2012; Jin et al., 2015). Teacher learning progressions can show how teachers' knowledge or performance can progress in time (Schneider & Plasman, 2011, Windschitl et al., 2012). Some of the unique features of learning progressions that were underlined by the current study can be stated as: (a) creation with an iterative cycle of refinement (Alonzo & Steedle, 2009; Shea & Duncan, 2013; Stevens et al., 2010), (b) representation of successive sophistication (Rivet & Kastens, 2012), (c) serving as templates for assessment and instructional products, and (d) being grounded in research (Duncan et al., 2009; Stevens et al., 2010). Learning progressions approach was utilized to offer a unique perspective innovative for teacher development on K-12 engineering education

There were efforts in the literature towards developing and presenting systematic rubrics and examinations to evaluate teachers' understanding of the engineering design process (Bailey & Szabo, 2007; Duncan et al., 2011) and teachers' engineering design performance (Wendell, 2014). The current study contributed to the literature by introducing learning progressions that can be thought of as theoretically and empirically validated versions of rubrics. There was not particular learning progression on engineering design process understanding however the focus on similar systematic rubrics highlighted the critical contribution of the current study. The systematic rubrics in the literature presented how an expert level knowledge or understanding looks like. However, these were created with a top-down approach in that, no empirical data was used for validation of what the levels describe. The current study introduced a distinguishing perspective at this point. The levels were created with help of existing informative literature, expert opinion, and collection and analysis of empirical data.

The current study developed and implemented core elements of teacher PD programs on K-12 engineering education. This effort brought about what to highlight in delivery of such programs. To continue with the teacher PD program delivered in the study, the characteristics of effective training programs included incorporating appropriate knowledge, having necessary materials and outside speakers and/or experts, and having a long-term design (Griffin & Barnes, 1986). The current study addressed these points as well as some of the weakness of teacher PD programs such as insufficient professional trainers, lack of collaboration between teachers, and insufficient feedback to the participant teachers and lack of systematic training models, need for more teacher PD programs on engineering content, or relevant pedagogical approaches, and teachers' having requirement to participate to the PD program, need for use of more systematic tools to measure teacher progress (Bayrakçı, 2009; Clarke & Hollingsworth, 2002; Guskey, 2002; Hynes & Santos, 2007; Kennedy, 2006; Lee, 2005). The core elements developed and practices in the current study revealed a process of conceptually basing a teacher PD program on K-12 engineering education on strengths found in the literature.

It can be concluded that future reforms in teacher education on K-12 engineering education should increase focus on careful assessment of teacher learning. Learning progressions can help to point to this need in a comprehensive manner.

5.4. Implications for Practice

The current study aimed to contribute to the learning progressions literature by focusing on teacher improvement for K-12 engineering education. The results offered examples of learning progression development, validation, and alignment of learning progression, instruction and assessment. Future learning progression development studies can be inspired with the systematic development and validation procedures. The current study illustrated two of the four goals of learning progressions; teacher development and short-term formative assessment (Kobrin et al., 2015).

Engineering education has great potential to increase conceptual understanding of STEM disciplines. With the finalized versions of the learning progressions, critical tools will be presented to K-12 engineering education literature concerned with teacher development. Again for development of teachers, the current study presented and implemented core elements (see Figure 2) of teacher PD programs than can be followed by other authors to deliver a similar program on K-12 engineering education. Teachers can increase their recognition and understanding of engineering with participation to PD programs (Duncan et al., 2011; Nugent et al., 2010). In order to effectively integrate engineering to K-12 level education, qualified teacher PD programs are needed (Dyehouse et al., 2014). The model of core elements is expected to guide PD designers but it should be noted that PD program design and delivery is a complicated process. Thus, future researchers should take into account that there can be revisions to the core elements as contextual and individual factors are considered. The core elements need to be tested in different contexts and to be refined. Conceptually basing the teacher PD program on; a) descriptions of the engineering design process as presented in Chapter 2; Review of the Literature, b) the core elements of teacher PD programs created and presented in Figure 2, and c) the second version of the learning progression on engineering design process understanding also can serve as a proper example for teacher PD program designers.

The current study can help assess teaching progress by exemplifying empirically aligned learning progressions while pointing to the need for more valid and reliable instruments on teacher improvement on K-12 engineering education. Where teachers stand in terms of their attitudes and understanding can more validly be documented with learning progressions. The interpretation of teachers' attitudes and understanding will not be limited only to a score of an instrument as in classical measurement approaches, but further comments on the respondents can be possible with learning progressions approach. Teachers' level of attitudes and understanding of the engineering design process can be more systematically documented and more interpretations can be made in terms of giving feedback. The survey developed can be validated by future researchers in different contexts. For the teacher learning progression on engineering design process understanding, an instrument can be developed which might be composed of Ordered Multiple Choice (OMC) items (see Figure 4). To be better useful for teacher development, learning progressions can be accompanied by tools; associated instruments (e.g. Alonzo & Steedle, 2009; Furtak et al, 2012; Hadenfelt et al., 2016). In the case of OMC items (Hadenfelt et al., 2016), much like multiple choice items, each item has response options, each aligned with one level of the learning progression (see Figure 4). This way, teachers taking the instruments can directly be put on their progression levels and feedback can be provided. Such learning progressions aligned with their instruments can be considered as important contributions to the literature on science teacher development. The current study presented the first research cycle that would finally lead to the final version of the learning progressions and their associated instruments.

The findings served as an example on the use of instructional contexts and curricular activities to validate learning progressions in a clear way (Jin et al., 2013; Songer et al., 2009). The findings and the products of the study along with an example of a PD program can provide a foundation for further improving K-12 engineering education and teacher preparation. Interested educators can implement similar programs by also focusing on monitoring the progress of teachers. The results of this study can contribute to the field of science teacher education with the learning progressions and the instruments produced on K-12 engineering education. The results can guide other researchers who are interested in designing a teacher PD program on K-12 engineering education. As the scope of research and practice efforts are systematically presented; results can contribute to the preparation of more effective teacher development programs.

With the work on learning progressions, research-based practice can be achieved (Duncan & Rivet, 2013) with asking questions on the steps taken to achieve a certain level of understanding (Corcoran et al., 2009). The current study presented examples to such research-based practice with the validation strategies followed. Overall supporting learning progression levels with empirical data was illustrated with various data collection strategies. The teacher PD program exemplified how a learning progression can be aligned with an instructional context and curricular activities. Lastly, development of a learning progression with its associated survey showed ways of validating a learning progression and what to pay attention to in the refinement procedures. The final versions of the learning progressions and their associated instruments with future studies can be used to track the changes in teachers'' attitudes and understanding with participation to the teacher PD program. Teachers can be measured along the continuum from negative attitude to positive attitude, and from novice understanding to mastery understanding which will contribute to their improvement in K-12 engineering education.

The empirical alignment between the teacher learning progression levels, the items of the survey, and the PD program should be improved. Follow-ups can be integrated into the structure of the PD so that teachers can have the chance to implement engineering activities in their classrooms with the guidance of the PD trainers following what they learn in the PD program. In addition, discussions on school context, classroom climate, and possible barriers in schools can be included. The written assessment results had highlighted the role of school context in making as teachers reflected on their attitudes. Teachers referred to time and the effort they could need in preparation of the engineering activities. Such barriers teachers face can be effective in their adoption of a particular strategy (Blackwell et al., 2013). The effect of school context was placed in the learning progression levels as well however the survey items were poor in reflecting this point. Even for the most dedicated teacher to implement a certain strategy, poor school and classroom conditions can be reasons to influence the attitude of the teachers (de Souza Barros & Elias, 1997). Existence or lack of administrative support was also among the factors that effects teachers' attitudes (Yaşar et al., 2006). Items concerned with the barriers of time and effort, and school context could be given a larger role in the next version of the survey.

Windschitl et al. (2012) developed a teacher learning progression on teachers' performance on a set of instructional practices. When the sample studied is in-service teachers, working on performance might be very beneficial as these teachers are practicing in real classrooms everyday. The current study concentrated understanding of a core idea selected, engineering design process, rather than a performance. This performance could be the application of the engineering design process by the teachers. Evidenced by Table 2, many teacher PD programs investigated teachers' ability to teach engineering in classroom (e.g. Cejka et al., 2006; Cunningham et al., 2007). As in the case by Windschitl et al. (2012), teachers can be observed and videotaped in development of a teacher learning progression. This can be a concern for future studies, since in-service teachers are practitioners and they can benefit from a learning progression on their performance of engineering design applications. Such research can finally result in a very comprehensive learning progression that will include both content; to what extent engineering design process is understood, and performance levels; how successfully the engineering design steps are enacted. The literature contained similar learning progressions that included both a content and a skill component in one learning progression (Duncan et al., 2009; Songer & Gotwals, 2012). Investigating teachers' performance levels as they follow engineering design process can be the next focus. Since the current study is interested in in-service teachers, who are practitioners all the time in their classrooms, investigating not only their level of understanding but also their performances can be worthwhile.

The examples in the learning progressions literature on learning progressions including both content and skill development together can be examined.

To conclude, for teacher PD program organizers the study can be leading since there is a need for more measurement tools on teachers' attitudes towards K-12 engineering education (Lachapelle et al., 2014; Yaşar et al., 2006; Yu et al., 2012). For policy makers revealing teachers' attitudes validly is critical as it is a newly emerging area for science teachers especially in the national context. The final version of learning progression and surveys are expected to be useful to integrate engineering successfully to science education. teacher improvement on engineering is critical for both national and international contexts (MoNE, 2016, 2017; NRC, 2009, 2012, 2014; Yu et al., 2012). The final version of learning progression, PD and associated instrument are expected to be useful to integrate engineering successfully to science education. Programs intended to be educational can support teachers' ongoing learning (Schneider & Plasman, 2011).

5.5. Implications for Future Research

Integration of engineering to K-12 level education can have a positive impact on students from various aspects; interest in engineering careers, technological literacy, engaging students in real-world discussions, and conceptual understanding of STEM disciplines (NGSS Lead States, 2013; NRC, 2009; NRC, 2012). The aspects underlined the importance of engineering for K-12 students. These aspects are not only limited to science education and science classrooms. Although the current study had a focus on K-12 science education, engineering design process is useful for teaching a diversity of mathematical concepts to K-12 students by engaging them in activities (Narode, 2011). Since most of the science and also mathematics teachers do not have sufficient knowledge and experience to teach engineering in their classes (Wang, Moore, Roehrig, & Park, 2011), mathematics teachers' improvement in terms of their positive attitudes and understanding of engineering design can contribute to successful integration of engineering to more K-12 classrooms. Engineering education is becoming more prevalent in K-12 classrooms which underlined the importance of preparing competent teachers in STEM fields (Guzey et al., 2014).

The methodology followed exemplified the fact that developing learning progressions requires working with large set of participants and completing data collection and analysis cycles (Mayes et al., 2014; Mohan et al., 2009; Songer & Gotwals, 2012). This was a strength of the current study to present learning progressions with refinements and different versions. Learning progressions can be developed solely on examination of the existing research findings (Duncan et al., 2009; Neumann et al., 2013). However, supporting the learning progression development with empirical data adds to its validity. With the collection and analysis of data, learning progression can be refined many times (Mayes et al., 2014; Mohan et al., 2009). In validation or refinement of the learning progression levels, associated assessment instruments, curricular activities or teaching interventions can be developed where the learning progression can serve as a template for all (Jin et al., 2013; Songer et al., 2009). Some studies developed an assessment instrument that was aligned with the levels of the learning progressions (Black et al., 2011; Jin & Anderson, 2012; Schwarz et al., 2009). The second group of studies developed an instructional intervention along with an assessment instrument. They created teaching experiments; developed curricular units (Songer & Gotwals, 2012) or modified instruction (Plummer & Maryland, 2014). The current study was a good example of all these frequently used strategies in learning progression development.

The format and structure of the teacher learning progression is innovative for similar studies on attitudes. The teacher learning progression on attitudes had a format that exceeded the existing construct maps; learning progressions on attitudes. Because formerly, in such learning progressions on attitudes, the levels did not even have particular descriptions, such a format is typical of learning progression on understanding of a certain content. Therefore, this format is contributing to the literature. However, it needs to be improved with more descriptions in the levels. This can be possible with the final validations of the levels and the items with refinement studies.

The teacher learning progression followed the validation strategies of developing an associated instrument, analyzing data with Rasch analysis, and using teacher PD program as a context. As another alternative, there might be no PD program provided to any teacher group, where data will be collected from teachers known to implement engineering activities in their classrooms. This way, there might be an enhanced empirical alignment between the learning progression and the survey can be achieved. Because as the participant teachers all will have prior knowledge, background and experience with engineering, they can reflect a variety in terms of attitudes. Later, the revised version after analysis of a large sample size can again be tested in the PD environment. For the third part; learning progression and survey, refining the survey so that it includes Guttmann type items especially for the aspects where the survey was unsuccessful in distinguishing teachers; interest and motivation to learn about engineering practices and integration of engineering, and contribution of engineering to development of students and improvement of society can be a good strategy. Overall, more number of harder to agree items are needed. For the learning progression, the recommendation included in this proposition was already applied. The levels were refined so that the aspect; interest and motivation to learn about engineering practices and integration of engineering is solely place in the lower three levels of the learning progression. Such a new format needs to be tested and validated with the third version of the survey. In this new version of the survey, items on teacher comfort in teaching, and teacher efficacy can be included because the alignment between items on teaching were relatively more successful according to the results.

K-12 engineering education, and integration of engineering practices to science instruction is a new and innovative pedagogic approach for teachers. As teachers were not familiar with engineering practices and it is new for especially the Turkish context, it is very appealing to teachers. However, according to attitude change models, teachers need time to gain and reflect on experiences in school context. Attitude is effected by changes in behavior. Therefore, maybe a true reflection of teacher attitudes can be captured after a certain amount of time. Maybe following the execution of the new middle school science curriculum in schools, the item and the learning progression can give better results with responses of teachers.

Although the current study produced three versions of the learning progression following refinements, the third version still needs to be validated. The future validations can be through providing the teacher PD to other groups of teachers and again use teacher logs and clinical interviews. In this validation the teacher PD program will be tested as well, with refinements following the results of the study some of which can be; more focus on a variety of examples for criteria and constraints, having teachers present their prototypes in both of the engineering design challenges, and putting more emphasis on the engineering design steps, retesting, evaluations, presenting, communicating findings and marketing. As a second alternative, OMC items associated with the learning progression can be developed and tested with with a large sample of teachers, not necessarily participating to the teacher PD program.

The variety in the conclusions reached in comparison to the upper anchor of the second and third versions of the learning progression need examination by researchers interested in building on this study. The upper anchor of the first and second versions of the learning progression were mainly based on informative standard documents and expert opinion through item paneling. These were the expectations a mastery level teacher could reach. However, the group of teachers in the current study were revealed not to reach some of the aspects of the upper anchor, which resulted in the refinement of the upper anchor. Some of the aspects were still having confusions with some of the engineering design process steps, being limited in terms of exemplifying criteria, constraints, and tradeoffs, and mistakes in the order of the steps. Such aspects might be better improved in the future teacher PD programs so that a more comprehensive upper anchor as suggested by the literature can be reached by the teachers.

To conclude, for learning progression developers who are interested to work on attitudes the format and structure of the teacher learning progression can be considered innovative compared to similar studies on attitudes (Mahat, 2008; Nguyen & Griffin, 2012) with inclusion of details in the levels.

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APPENDICES

APPENDIX A

WRITTEN ASSESSMENT QUESTIONS

1. I feel motivated / not motivated to improve myself in K-12 engineering education.

Please explain your answer briefly with reasons.

2. I feel motivated / not motivated to implement engineering activities in my classroom.

Please explain your answer briefly with reasons.

3. What do you think on the possible contributions of K-12 engineering education?
4. Can you give some examples of support you will need to implement engineering activities in your classroom?
5. My overall attitude on K-12 engineering education is positive / negative.

Please explain your answer briefly with reasons.

6. The focus of science education has been fundamentally changing within the past few years. In particular, there is a movement towards building knowledge in use and towards STEM (Science, Technology, Engineering and Mathematics) education. In this respect, engineering is gaining a major place in science education.

   Do you agree with this movement towards implementing engineering concepts and practices in science education? Please provide justification for your answer.

7. What do you think are some reasons that engineering practices are integrated to science instruction?

In this lesson, 8^{th} grade students will build a scooter that can go farther as possible. The materials including cardboard, sticker, rubber band, wooden sticks will be provided. The students will work in groups.

The students will examine their knowledge on energy conservation, friction, velocity and time. They will play with the variables such as type of material or diameter of wheels and finalize their scooters. At the end of the lesson, the best scooter will be selected based on the distance it can travel.

1. What engineering knowledge/concepts do you believe students can learn in a science lesson described above?

2. How do you think this lesson that is incorporating an engineering activity is different than a typical science lesson?

3. What do you know about the engineering design process?

4. What are the important components of the engineering design process?

APPENDIX B

COGNITIVE INTERVIEW PROTOCOL

WELCOME

Greetings. The goals of the interview are clarified. A warm rapport and atmosphere is established. Information is provided on cognitive interviews and its general procedure. Informed consent is taken from the participants on voice recording.

WARM UP

I am interested in what you think about the items in this instrument as we go though them together.

Let's try a warm up exercise:
Let's remember the last time you did grocery shopping. Tell me anything aloud that you think right now. How was the place like? Who were there? What were they wearing? What could you smell? State as much detail as you can please.

THINK ALOUD QUESTIONS

1. Please tell me everything you are thinking as you answer the question.
2. When you answered the item, what were you thinking?
3. How did you go about answering that question?
4. What are you thinking now, as you read the item?
5. What were you thinking about what the item is asking from you?
6. What is this question asking?

VERBAL PROBES

1. What to you is X?

2. How did you decide that was/ was not the correct answer?
3. What is this question asking?
4. What was your strategy for answering this way?
5. Was is easy or difficult for you to answer this question?
6. How sure are you of this answer?
7. How did you arrive at this answer?
8. How did you feel about answering this question?
9. I noticed you hesitated before you answered—what were you thinking?
10. What does X mean to you? How did you remember that?
11. Why do you say that?
12. What would it take for you to say '......'?
13. What time period were you thinking about?
14. Can you tell me more about that?
15. Can you repeat the question I just asked in your own words?
16. Was the intent of the question clear?

CLOSURE

To what extent attitudes towards K-12 engineering education were addresses?

What aspects were not included?

What would you add to this instrument?

What would you exclude?

What other comments do you have?

APPENDIX C

TEACHER LOGS

Uygulamanın amacı: Mülakatın amacı mühendislik tasarım eğitimi, mühendislik tasarım süreci uygulama adımları konularında sizlerin bilgi ve deneyimlerini anlamaktır.

SORULAR

1. Mühendislik tasarım sürecinin amacı nedir?

2. Mühendislik tasarım süreci hangi uygulama adımlarından oluşur?

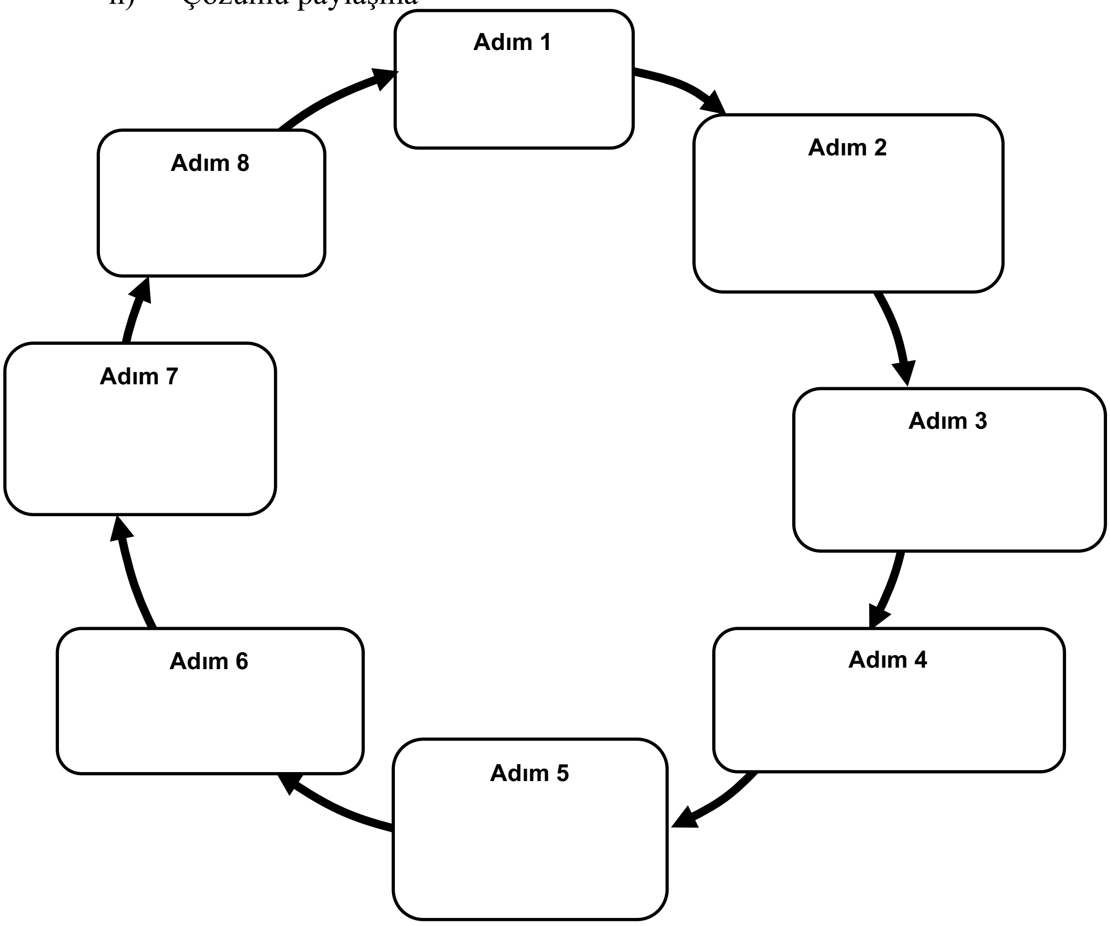
3. Yazdığınız uygulama adımlarını sıraya sokunuz.

4. **Aşağıda mühendislik tasarım sürecinin uygulama adımlarını içeren modellerden biri yer almakta. Uygulama adımları yanlış bir sırayla verilmiş durumdalar. Lütfen figür üzerinde doğru şekilde sıralayınız.**

Tüm seçenekler kullanılmayacaktır.

a) Çözümü test etme ve değerlendirme
b) Olası çözümler geliştirme
c) Gözlem yapma
d) İhtiyacı veya problemi belirleme
e) İhtiyaç veya problemle ilgili araştıı
f) Prototip geliştirme
g) Deney yapma
h) Çözümü paylaşma

i) Tüm çözümleri deneme
j) Problemi çözme
k) Hataları ortaya koyma
l) Deney yapma
m) Farklı disiplinlerden yararlanma
n) Tekrar tasarlama
o) Ürünü teknolojiye



5. Mühendislik tasarım süreci için **"sınırlılık"** ve **"kriter"** kavramları ne anlama gelmektedir? Aralarındaki ilişkiyi kısaca açıklayınız.

6. Bir problem senaryosunda olabilecek kriterlere ve sınırlılıklara örnek veriniz.

Sınırlılıklar:

Kriterler:

7. Mühendisler tasarımlarını gerçekleştirirken mühendislik tasarım süreci doğrultusunda çalışırlar. Bu surece ait bildiğiniz özellikleri yazınız.

8. Mühendislik tasarım sureci genellikle: (boşluğu aklınıza gelen ifadelerle doldurunuz)

....

....

....

....

Tamamladığınız Rüzgar Türbini tasarımı etkinliğini düşünerek yanıtlayınız.

1. Mühendislik tasarım sürecini nasıl kullandınız? Hangi uygulama adımlarını etkin olarak kullandınız, kısaca açıklayınız?

2. İleride mühendislik tasarım sürecini hangi uygulama adımlarında daha iyi olmanız

gerekir? Neden?

3. Karar verirken optimizasyon ve ödün verme stratejilerini nasıl kullandınız?

4. Bir tasarım yaparken neleri dikkat edilmesini önerirsiniz?

APPENDIX D

CLINICAL INTERVIEW PROTOCOL

Task 1: Engineering Design Process Model

a. Mühendislik tasarım sürecini bir model ile gösteriniz.

Çizim sırasında ek sorular sorulur. Çizdiği adımlar ile ilgili neden olması gerektiğini düşündüğü sorulur. Eksik bıraktığı adımlar olabilir mi diye sorulur.

b. Tüm tasarım süreci modelleri çizilen bu modelin aynısı mıdır?

Farklı modellerin içerikleri sorulur. Eğer farklı modellerle ilgili bilgisi varsa onların içerikleri, uygulama adımları sorulur. Bilgisi yoksa nasıl farklılıklar ve benzerlikler olabileceği sorulur. Temelde hepsinde neler aynı olabilir?

c. Boşlukları tamamlayınız.

Mühendislik tasarım süreci ile ilerlenirken tüm uygulama adımları tamamlanır. Bu esnada……………………………………………………………………………… ……………dikkat edilmesi önemlidir. Tasarım sürecini tekrar tamamlamanın amacı ……………………………………………………………………………………… ………

Herhangi bir yanıt verilemezse sınıfta yapılan rüzgar türbini tasarımı ve araba tasarımı etkinlikleri hatırlatılır. O tasarım görevlerini tamamlarken nelere dikkat ettikleri, ve amaçlarının ne olduğu sorulur. Birden fazla yanıt vermeye yönlendirilir. Dikkat edilecek tek bir özellik söylenirse Başka neler olabilir diye sorulur.

d. Süreci ikinci veya üçüncü kez tamamlarken tüm adımlar yine baştan sona tamamlanmak zorundadır.   Doğru Yanlış

   Verilen yanıt üzerinden Neden böyle düşünüyorsunuz?

e. Sizce mühendislik tasarım süreci (engineering design process) neden kendini tekrar eden döngüler seklinde takip edilmektedir (being iterative)?

Task 2: Engineering Design Process Steps and Concepts

a. Mühendislik tasarım sürecinde neden kriter ve sınırlılıklar önemlidir EVET HAYIR

   Kriter ve sınırlılıkların farkı nedir. Kriter ve sınırlılıklara örnek vermezse örnek istenir.

b. Mühendislik tasarım sürecinde ödün verme stratejisi önemlidir EVET HAYIR

   Kriter ve sınırlılıklar ilişkisi nedir eğer mühendislik tasarım süreci üzerinden gidilmezse, tasarım süreci ile ilişkisi ve katkısı sorulur.

c. Probleme olası çözümler üretmek ne demektir?

   Eğer bahsedilmezse problem belirleme ve *Kriter ve Sınırlılıklar ilişkisi sorulur. Bunu örneklendirmesi istenir. Problem çözme basamağı ile bunların ilişkisi nedir*?

d. Çizdiğiniz model üzerindeki tüm uygulama adımlarını teker teker açıklayalım.

   Her adımda neler yapılacağını açıklaması istenir. Eğer modelde çok eksik varsa ve açıklamakta zorlanıyorsa NASA Let it Glide modeli gösterilir ve onun üzerinden açıklamalar yapılır. Hızlı geçtiği adım olursa, burayı hızlı geçtiniz, sizce daha mı kısa sürüyor veya daha mı az önemli.

e. Aşağıda mühendislik tasarıma ilişkin verilen maddelerden size göre en önemli 5 tanesini belirleyiniz.

Neden önemli olduğunu düşündükleri sorulur. Toplam 5 tane belirleyemezse ek olarak bazıları işaret edilir ve açıklattırılır. Sizde bu seçtiklerinizle ilgili eğitim başında ve sonunda nasıl bir değişim var sizin açınızdan? *Tabloda göremediğiniz size göre önemli eksik ifade, kavram var mı* ?
Hangi şıklarla arada kaldınız?

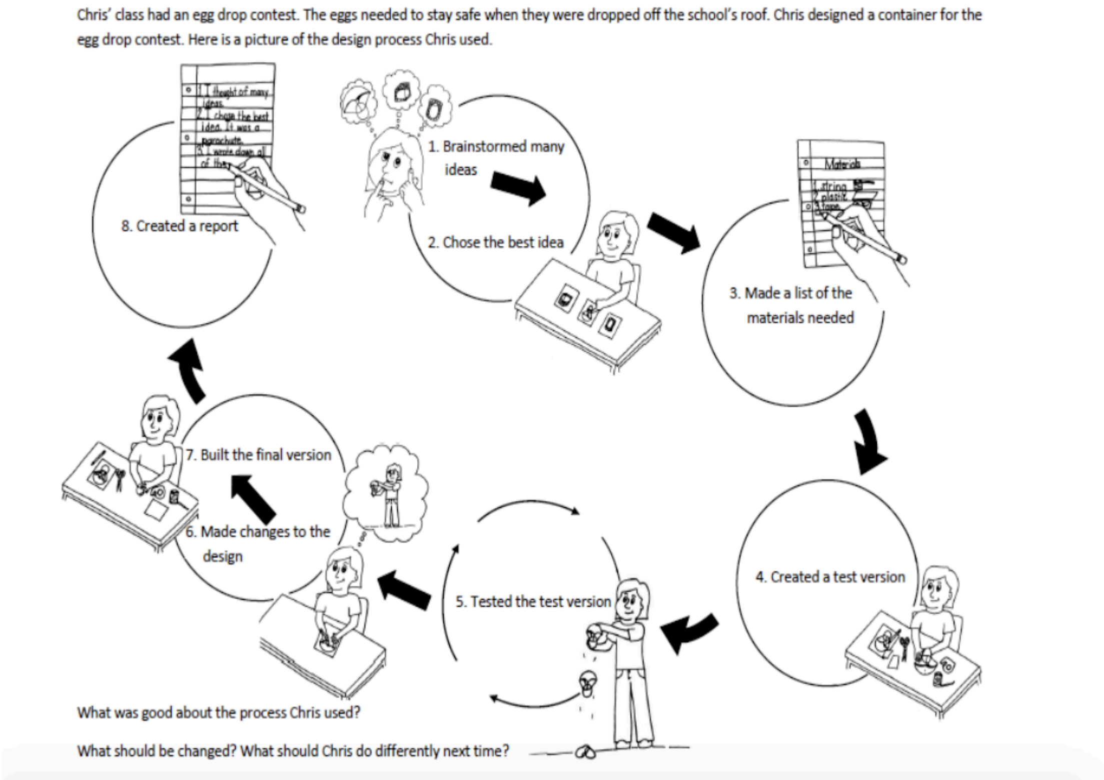
Task 3: Evaluating a Complete Engineering Design Process

a. Tamamlanmış Egg Drop Container görevi gösterilir.

Bu görev size neleri düşündürdü. Aklınıza gelen her şeyi söyleyin lütfen. İlk soruda çizdiğiniz modele göre aşamaları anlatınız. Güçlü ve zayıf yönlerin üzerine gidilir.

b. Bu kez NASA let it glide rubric gösterilir ve onun üzerinden değerlendirme alınır.

Değerlendirmekte zorlanırsa ruric in mastery level açıklanır ve onun üzerinden yapması istenir. Bu görev size neleri düşündürdü. Aklınıza gelen her şeyi söyleyin lütfen. İlk soruda çizdiğiniz modele göre aşamaları anlatınız. Güçlü ve zayıf yönlerin üzerine gidilir. (Cardella et al., 2014, p. 4)



Atölye sırasında yapılan iki tasarım etkinliğinden birini seçmesi istenir.

c. Bu tasarım görevinde üzerinde çalıştığınız problem neydi?

İfade etmekte zorlanırsa NASA let it glide problem yazma ifadesi gösterilir ve buna oturtması istenir.

d. Kriterler ve sınırlılıklar nelerdi?

Eğer ikisini ayırt edemezse tek tek tekrar sorulur. Görüşmenin başından beri konuşulanlar hatırlatılır. Zorlanırsa daha önce katıldığı farklı tasarım etkinlikleri varsa düşünmesi istenir. Use a little prompt mesela sınırlılık bizi sınırlayan birşey tasarım yaparken bu ne olabilir. Aynı şekilde kriter başarıya ulaştıran şeydir bu ne olabilir.

e. Tradeoff yani ödün verme stratejisini nasıl kullandınız?

Zorlanırsa görüşmenin başından beri konuşulanlar hatırlatılır. Gerçek hayatta ödün vermek ne demektir oradan akıl yürütmesi yapması önerilir.

f. Bu tasarım görevini yeniden yapıyor olsaydınız neleri farklı yapardınız?

   Güçlü ve zayıf yönler nelerdi

NASA Let It Glide Açıklamalar (NASA, 2012)

ADIM1: **İhtiyacı veya problem belirleme –** Tasarım takımı kendi cümleleri ile problemi ifade eder. Örnek olarak ....gerçekleştirecek bir .... nasıl tasarlayabilirim

ADIM2: **Problemi araştırma –** Tasarım takımı interneti, kaynakları, kütüphaneyi ve alanında uzmanlarla yaptıkları görüşmeleri kullanarak problemin güncel olarak nasıl çözüldüğünü, benzer problemlerin nasıl çözüldüğünü, ve genel olarak gerekli bilgileri araştırırlar.

ADIM3: **Olası çözümler geliştirme –** Tasarım takım üyeleri matematik ve fen alanındaki bilgileri üzerine beyin fırtınası yaparlar ve problemi çözebilecekleri yolları tartışırlar. En makul ve umut veren çözümler yazılır. Birden fazla makul çözüm ortaya konur. Doğru bir şekilde, tasarım kavramları çeşitli çizimlerle sunulur.

ADIM4: **En iyi çözümü seçme –** Takım üyeleri tartışarak fikirlerini ifade ederler. Her çözüm önerisinin güçlü ve zayıf yönlerini etraflıca analiz eder. Problemin kriter ve kısıtlamalarını tüm yönleri ile değerlendirerek uygulanabilir ve makul bir çözüm seçer. Neden bu çözümün seçildiği açıklanır.

ADIM5: **Prototipi yapılandırma –** Tasarım çözümünün modeli yapılır. Gerekli malzemeler kullanılır. Prototip görevin kriterlerini net ve detaylı bir şekilde yerine getirir.

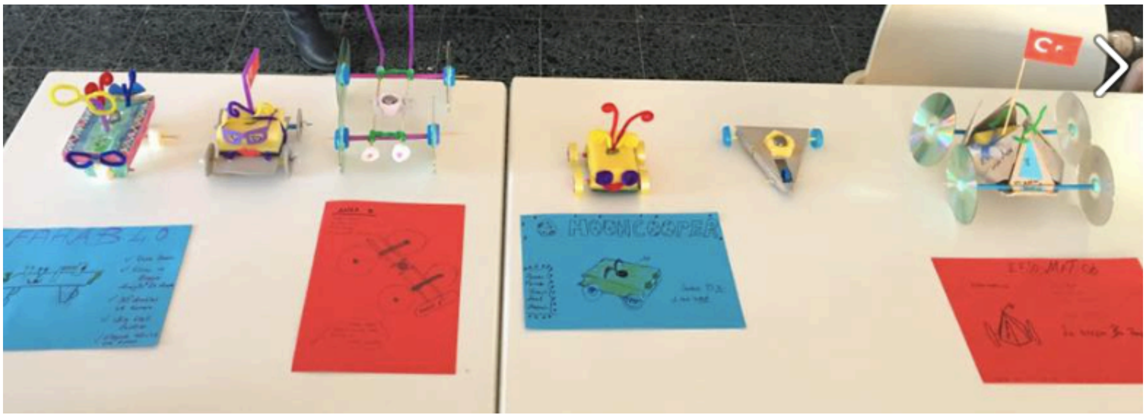
ADIM6: **Çözüm/leri test etme ve değerlendirme –** Çözümün ne kadar başarılı olduğu ortaya konur. Veriler elde edilip kaydedilir. Veriler yeniden tasarlama sürecinde açık bir biçimde yol gösterici olur.

ADIM7: **Çözümleri sunma –** Tasarım takımı test aşaması ile elde ettiklerini, öğrendiklerini paylaşır. Çözümleri ile ilgili sunum yapılır. Test sonuçları doğru raporlanır ve nasıl gelişim göstereceği açık bir biçimde paylaşılır. Farklı takımlardan geri bildirim alınır.

ADIM8: **Yeniden tasarlama –** Tasarım takımı tasarımlarını nasıl güçlendirebileceklerini konuşurlar. Probleme geri dönülür, yeniden tasarlama süreçlerinin kriter ve kısıtlamaları karşıladığından emin olunur. Tasarım sürecine yeniden başlanır.

APPENDIX E

TEACHER PD PROGRAM PHOTOS



ODTÜ

Fen Bilimleri Öğretmenlerine Yönelik Mühendislik Tasarım Atölyesi

APPENDIX F

"SCIENCE TEACHERS'ATTITUDES TOWARDS K-12 ENGINEERING EDUCATION SURVEY" USED IN TEACHER PD PROGRAM

Bu ölçeğin uygulanma amacı siz değerli öğretmenlerin '**Fen Eğitiminde Mühendislik Tasarım Uygulamaları'** na karşı tutumları hakkında bilgi sahibi olmaktır. İsminizi belirtmenize gerek yoktur. Yanıtlarınız ölçeğin geliştirilmesine katkı sağlayacaktır. Katılımınız için çok teşekkür ederiz.

Araş. Gör. Canan Mesutoğlu (mcanan@metu.edu.tr)
Yard. Doç Dr. Evrim Baran (ebaran@metu.edu.tr)
ODTU Eğitim Bilimleri

Ölçek maddeleri	**Tamamen katılmıyorum**	**Katılmıyorum**	**Kararsızım**	**Katılıyorum**	**Tamamen Katılıyorum**
1. Derslerime mühendislik tasarım sürecinin dahil edilmesi konusunda kendimi mesleki olarak geliştirebileceğim eğitimlere ve seminerlere katılmak ilgimi çeker.					
2. Sınıflarımızda mühendislik tasarım etkinliklerini uygulamamız, öğrencilerin teknoloji ve mühendislik alanlarındaki mesleklere karşı ilgilerini artırır.					
3. Fen eğitiminde mühendislik tasarım uygulamaları konulu kaynaklar (kitap, dergi, video, görsel materyaller gibi) ilgimi çeker.					
4. Derslerimde uygulayabileceğim mühendislik tasarım etkinlikleri konusunda kendimi geliştirmek beni heyecanlandırır.					
5.Mühendislik tasarım etkinliklerinin öğrencilerin takım çalışması becerilerini geliştireceğini düşünüyorum.					
6. Okul öncesinden başlayarak 12. sınıfa kadar fen derslerine mühendislik tasarım sürecinin dahil edilmesi toplumumuzu pozitif yönde etkileyecektir.					
7. Örnek alabileceğim mühendislik tasarım etkinliklerini araştırmaktan keyif alırım.					

8.Öğrencilerin mühendislik ve tasarım becerilerinin gelişmesini önemli buluyorum.					
9. Okul öncesinden başlayarak 12. sınıfa kadar öğretim programlarında mühendislik uygulamalarına yer verilmesi gerektiğine inanıyorum.					
10.Öğrencilerime mühendislik tasarım sürecini öğretme konusunda hevesliyim.					
11. Fen öğretim programına mühendislik tasarımın dahil edilmesinin önemli olduğunu düşünüyorum.					
12. Mühendislik tasarım etkinlikleri, öğrencilerin yaratıcı düşünme becerilerini geliştirebilmeleri açısından önemlidir.					
13. Okul yönetimim tarafından bir mühendislik tasarım etkinliği hazırlamam istenirse, verilen görevi yapmaktan kaçınırım.					
	Tamamen katılmıyorum	**Katılmıyorum**	**Kararsızım**	**Katılıyorum**	**Tamamen Katılıyorum**
14.Öğretmenlere yönelik mühendislik tasarım uygulamaları konulu bir seminere katılım sertifikası alabilmek için katılırım.					
15. Mühendislik tasarım uygulamalarının öğretim programlarında yer almasının öğrenciler açısından olumlu olacağını düşünüyorum.					
16.Üniversite öncesi seviyelerde mühendislik tasarım uygulamaları, öğrencilerin disiplinler arası yaklaşımı anlamalarına katkı sağlar.					
17. Mühendislik tasarım uygulamalarının öğretim programlarında yer alması toplumsal sorunların çözümüne katkı sağlar.					
18.Mühendislik tasarım etkinliklerini yalnızca zorunlu durumlarda uygularım.					
19. Okul öncesinden başlayarak 12. sınıfa kadar mühendislik tasarım etkinliklerinin uygulanması ile öğrencilerin yenilikçi düşünme becerileri (inovasyon) gelişir.					
20. Mühendislik tasarım etkinlikleri, öğrencilerin var olan bilgileri ürüne dönüştürmesi açısından değerlidir.					

21.Ders saatlerinden sonra mühendislik tasarım etkinliklerinin uygulanacağı bir öğrenci kulübü oluşturmak ilgimi çeker.					
22.Öğrencilerimin problemlere bir mühendis gibi yaklaşmalarını önemli buluyorum.					

APPENDIX G

DOCUMENTS USED AT THE TEACHER PD PROGRAM

TASARLA | YAP | ÖĞREN

ATÖLYE ETKİNLİKLERİ VE KAYNAKLAR

Yararlanılan kaynaklar
Engineering is Elementary Örnek etkinlikleri, Vernier Araçları Internet sitesi, Lawrence Hall of Science Etkinlikleri, NASA websitesi STEM etkinlikleri

ODTU BILTEMM ve ODTU RUZGEM işbirliği ile Proje ODTU BAP tarafından desteklenmektedir.

Mühendislik kavramları

- Tasarım
- Mühendisliğin doğası
- Farklı mühendislik dalları (bilgisayar müh., telekominikasyon müh., jeofizik müh., inşaat müh., çevre müh., tekstil müh., gıda müh., nanomühendislik, ziraat müh. gibi)
- Atölye odağındaki mühendislik dalları: Makina müh., havacılık ve uzay müh., aerodinamik müh.
- Mühendislik tasarım süreci
- Teknoloji
- Problem belirleme / problem çözme
- Tasarımı geliştirme
- Sınırlılıklar
- Başarı kriterleri
- Ödün verme
- Takım çalışması

<u>Etkinlik 1</u>

Tasarım Görevi: Rüzgar Türbini Tasarlama

Genel Amaçlar

- Mühendislik tasarım sürecini uygulamak
- Rüzgarla ilgili materyaller ve rüzgar tutmada etkili olan faktörlerle ilgili öğrenilen ön bilgiyi tasarım yaparken kullanmak
- Rüzgar türbini tasarlarken birden farklı tasarımı hayal edebilmek
- Kullanılacak malzemeleri ve tasarım çizimlerini içeren detaylı bir plan ortaya koyabilmek
- Tasarımları yaratmak ve test etmek
- Tasarımların güçlü ve geliştirilebilir yönlerini ortaya koymak, ve
- Tasarımları geliştirmek için fikir üretmek

4. - 7. Sınıf:
Ünite: Fen ve Mühendislik Uygulamaları

Konu Alanı: Uygulamalı Bilim
Kazanımlar:

- Günlük hayattan bir problemi tanımlar.

a. Problemin günlük hayatta kullanılan veya karşılaşılan araç, nesne veya sistemleri geliştirmeye yönelik olması istenir.
b. Bu aşamada problemin malzeme, zaman ve maliyet kriterleri kapsamında ele alınması beklenir.
c. Problemlerin, eğitim-öğretim döneminin başından itibaren farklı dersler kapsamında yer alan konularla ilişkili olması tercih edilebilir.

- Problem için muhtemel çözümler üretir ve bunları karşılaştırarak kriterler kapsamında uygun olanı seçer.
- Ürünü tasarlar ve sunar.

a. Ürün tasarımı ve yapımı okul ortamında yapılır.
b. Öğrencilerden, ürün geliştirme aşamasında deneme yapmaları, bu denemeler sonucunda elde ettikleri nitel ve nicel verileri, gözlemleri kaydetmeleri ve grafik okuma veya oluşturma becerileriyle değerlendirmeleri beklenmektedir.

Kullanılabilecek Malzemeler

- Karton levhalar-mukavva
- Farklı renklerde kartonlar
- Cetvel
- Farklı boyda karton kutular (Süt kutusu, meyve suyu kutusu da olabilir)
- Bant
- Makas
- İp
- Çeşitli boy ve renklerde kâğıtlar
- Maket bıçağı
- Pet şişe
- Tahta çubuklar (dondurma çubukları),
- Pipet
- Kağıt bardak
- El işi kağıdı
- Plastik tabak
- Oyun hamuru
- Silikon tabancası ve silikon
- Pet şişe kapakları
- Likit yapıştırıcı

- Renkli plastik boncuklar
- Plastik şeffaf dosya
- Paket lastiği
- Aluinyum folyo
- Ispirto boya kalemleri renkli
- Strafor köpük
- Plastik poşet
- Çöp şiş
- Rüzgar türbinin dönerek taşıması beklenen yük

Tasarım Görevimiz: Rüzgar Türbini Tasarlıyoruz!

Yaşadığınız bölge elektriğini kömürden enerji sağlayan enerji istasyonlarından elde ediyor. Yerel şirketler kömür kaynaklarının tükendiğini ve elektrik üretmek için farklı yollara ihtiyaç olduğunu belirttiler.

Maliyeti düşük rüzgar türbinlerinin elektrik enerjisi üretmede faydalı olabileceği görüşü ön planda. Siz uzman mühendislerden bugün yerel şirketlerin ricası üzerinde farklı fikirler ve çözüm önerileri bekliyoruz !
Takım halinde basit malzemeleri kullanarak bir rüzgar türbini tasarımı ortaya koyunuz !

Bu tasarım görevi için kullanabileceğiniz bütçe en fazla 40 tl dir. Toplam iki buçuk saat süreniz bulunmaktadır.

Rüzgar türbininiz rüzgar enerjisini hareket enerjisine dönüştürmeli.

Zorluk seviye 1

Rüzgar türbininiz takımınıza verilen yükü ip yardımıyla kaldırabilmeli.

Zorluk seviye 2

Rüzgar türbininiz sizin seçeceğiniz daha ağır bir yükü ip yardımıyla kaldırabilmeli.

Malzemelerin Fiyatları

- Karton levhalar-mukavva

- Farklı renklerde kartonlar
- Farklı boyda karton kutular 10 TL
- İp
- Pet şişe 5 TL
- Tahta çubuklar (dondurma çubukları) 5 TL
- Pipet
- Kağıt bardak 5 TL
- El işi kağıdı
- Plastik veya kağıt tabak 5 TL
- Oyun hamuru 10 TL
- Plastik şeffaf dosya
- Paket lastiği
- Aluinyum folyo 10 TL
- Strafor köpük 7 TL
- Cam yünü
- Çöp şiş 5 TL
- Şişe kapağı 5 TL
- Strafor 5 TL

Problemi belirliyoruz

Verilen senaryodaki problem nedir? Problemi yazınız.

Problemin çözümü ile hangi ihtiyaçlar karşılanacak?

Problemin çözümünde hangi mühendislik alanları birlikte çalışabilir? Takımınızdaki üyelerin mühendislik alanlarını belirleyiniz.

Bu problemi çözmek için hangi bilgilere ihtiyacınız var?

Neler biliyoruz	Neler öğrenmek istiyoruz	Neler öğrendik (Etkinlik sonu doldurulacak)

İhtiyacınız olan bilgilere nasıl ulaşabilirsiniz?

Problemi çözmek için dikkat etmeniz gereken kısıtlamalar ve kriterler nelerdir?

Kısıtlamalar	Kriterler

<u>Ön Bilgilerin Yoklanabileceği Örnek Değerlendirme Soruları</u>

Rüzgar nedir?

a. Güneş enerjisi b. Fan tarafından oluşan bir kuvvet
b. Hareket eden hava d.......

Ruügarin enerjisi var midir?

a. Hayir rüzgar enerji kullanır
b. Hayir rüzgarin enerjisi olamaz
c. Evet rüzgarin guneş enerjisi vardir
d. Evet rüzgarin cisimleri hareket ettiren enerjisi vardir

Rüzgarin iş yaptigi hangisinde örneklendirilmiştir?

a. Bir odayı soğutan fan/ soğutucu
b. Bir tepeden aşağı inen bisikletli

c. Bir nehirden geçen bot
d. Rüzgar is yapamaz

Rüzgar türbini neler yapar?

Daha önce rüzgar türbini gördünüz mü?

Bir rüzgar türbinin iyi çalışması için hangi faktörler etkili olabilir?

Türkiye'de hangi bölgelerde rüzgar türbinleri ile enerji üretilmektedir?

Olası Çözümler

Problemi çözmek için olası çözüm önerileri nelerdir?

Sınırlılık, kriter ve ön bilgileri göz önünde bulundurarak hangi çözüm önerisinde karar kılıyorsunuz?

Hangi malzemeleri kullanacaksınız?

Takım olarak karar verdiğiniz tasarımınızı çiziniz.

Planımızı Uygulamaya Koyuyoruz

Tasarımımızı test edelim.

Tasarımınız yükü kaldırabildi mi? Evet ise kaç cm kaldırdı? ....

Tasarımın kanatları.........................

a. Dönmedi b. Fazla dönmedi c. Güzelce döndü

Tasarımı daha iyi hale getirmek

İlk denememiz sonucunda oluşan yeni sorularımız nelerdir?

Yeni tasarımınızı çiziniz.

<u>Final Tasarım Değerlendirme Soruları</u>

Tasarımınız yükü kaldırabildi mi? Evet ise kac cm kaldırdı?..............................

Tasarımın kanatları.........................

b. Dönmedi b. Fazla dönmedi c. Güzelce döndü

En iyi tasarımınız ayni zamanda ilk tasarımınız miydi?

a. Evet b. Hayır

Tasarımınızda neler iyi çalıştı?

Tasarımınızda neler iyi çalışmadı?

Bir sonraki tasarımınızı nasıl geliştirmeyi düşünüyorsunuz?

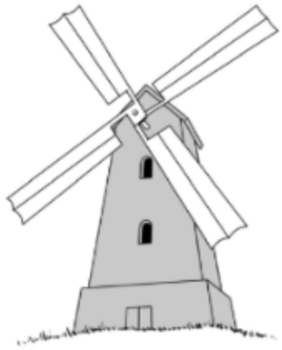
Sizce tasarımın iyi çalışması hangi değişkenler ile ilişkili?

Veri Tablosu

Denemeler	**10 saniyedeki dönme sayısı**
1	
2	
3	
Ortalama	
1 saniyedeki dönüş sayısı	

Yukarıdaki veri tablonuza göre, rüzgar türbininiz 5 saniyede kaç kez döner?

Eğer rüzgar türbininiz 1 saniyede yükü 20 cm kaldırıyorsa, 1 metre kaldırması için kaç saniye geçmelidir?



Başarı kriterleri

Yük kaldırma, yük miktarı

Estetik

Kullanışlılık

Dayanıklılık

Sunum- Katma değer

katma

Rüzgar türbini kısıtlamaları

	Tasarım 1	Tasarım 2
Maliyet en fazla 40 TL		
Yapım zamanı iki buçuk saat		
Kullanılan malzeme masadakilerle kısıtlı		

Rüzgar türbini basari Kriterleri

	Tasarım 1	Tasarım 2
Kanat mekanizması rüzgârla dönebiliyor		

Kaldırabildiği yük .... cm		
Farklı cins yükler kolay asılabiliyor		
Kanatlar rüzgarı tutuyor		
Estetik		

Karar verilen tasarim ve ödün verme konusunda aciklama:

Degiskenler

- Kanat sayisi
- Kanat sekli (acisi)
- Govde uzunlugu-kalinligi-sekli

Tasarım Görevimiz: Ay'da bir Geziye Çıkıyoruz!

- Ay'a nasıl iniş yapabiliriz?
  Ay'da nasıl yük taşıyabiliriz?

- Astronotlar Ay yüzeyinde farklı bölgelerde araştırmalar yapabilmek için bir ulaşım aracına ihtiyaç duyuyorlar. Apollo görevleri sırasında astronotlar **Lunar Buggy** isimli araçla uzay araçlarından kilometrelerce uzaklaştılar.

İlgili Video: ....

Siz uzman mühendislerden farklı fikirler ve çözüm önerileri bekliyoruz !

- Takım halinde basit malzemelerle astronotlar için bir ulaşım aracı **tasarlayan mühendisler** sizlersiniz! **Göreviniz** astronotları ve ihtiyaç duyacakları yükleri Ay yüzeyinde taşıyacak bir model araç **tasarlamak.**

Ekibinizle aşağıdaki şartlara uygun bir model tasarlamalısınız: (başarı kriterleri)

- Tasarımınız yükü **yapıştırmadan ve düşürmeden** taşıyabilmeli
- Tasarımın inişi güvenli olmalı
- Tasarımınız eğimli yüzeyden (rampadan) indikten sonra en az **30 cm yol**

alabilmeli

- **Malzemeler için bütçeniz 40 TL**
- Süreniz **2 buçuk saat**

<u>Etkinliğe İlişkin Örnek Fen Dersi Kazanımları</u>

Ünite adı Kuvvetin Ölçülmesi ve Sürtünme

Konu/Kavramlar: Sürtünme kuvvetini kaygan ve pürüzlü yüzeylerdeki uygulamaları, sürtünme
kuvvetinin günlük yaşamdaki uygulamaları.
F.5.3.2.1. Sürtünme kuvvetine günlük yaşamdan örnekler verir.
F.5.3.2.2. Sürtünme kuvvetinin çeşitli ortamlarda hareketi etkisini deneyerek keşfeder
Sürtünme kuvvetinin, pürüzlü ve kaygan yüzeylerde harekete etkisi ile ilgili deneyler yapılır.
F.5.3.2.3. Günlük yaşamda sürtünmeyi artırma veya azaltmaya yönelik yeni fikirler üretir.

Ünite adı Kuvvetin ve Enerji

Konu/Kavramlar: Enerjinin korunumu, sürtünme ile kinetik enerji kaybı, hava ve su direnci.
F.7.3.3.1. Kinetik ve potansiyel enerji türlerinin birbirine dönüşümünden hareketle enerjinin korunduğu sonucunu
çıkarır.
F.7.3.3.2. Sürtünme kuvvetinin kinetik enerji üzerindeki etkisini örneklerle açıklar.
a. Sürtünme kuvvetinin kinetik enerji üzerindeki etkisinin örneklendirilmesinde sürtünmeli yüzeyler, hava
direnci ve su direnci dikkate alınır.

<u>Etkinliğe İlişkin Örnek Matematik Dersi Kazanımları</u>

Doğal sayılarla işlemler yapmayı gerektiren problemleri çözer ve kurar.
Nicelikleri karşılaştırmada oran kullanır ve oranı farklı biçimlerde gösterir.
Orantıyı ve doğru orantılı nicelikler arasındaki ilişkiyi açıklar
5.2.3.3. Zaman .l.ü birimlerini tanır, birbirine d.nüştürür ve ilgili problemleri çözer.
6.1.3.4. Tam sayılarla toplama ve çıkarma işlemlerini yapar; ilgili problemleri çözer.
6.3.1.2. Komşu, tümler, bütünler ve ters açıların özelliklerini keşfeder; ilgili problemleri
çözer.

7.2.1.1. Gerçek yaşam durumlarına uygun birinci dereceden bir bilinmeyenli denklemleri
kurar.

7.2.1.2. Denklemlerde eşitliğin korunumu ilkesini anlar.
7.2.1.3. Birinci dereceden bir bilinmeyenli denklemleri çözer.
7.2.1.4. Birinci dereceden bir bilinmeyenli denklem kurmayı gerektiren problemleri çözer.

8.2.2.1. Doğrusal ilişki içeren gerçek yaşam durumlarına ait tablo, grafik ve denklemi
oluşturur ve yorumlar.
8.2.2.3. Doğrusal denklemlerde bir değişkeni diğeri cinsinden düzenleyerek ifade eder.

Malzemelerin Fiyatları

- Karton levhalar-mukavva
- Farklı renklerde kartonlar
- Farklı boyda karton kutular 10 TL
- İp
- Pet şişe 5 TL
- Tahta çubuklar (dondurma çubukları) 5 TL
- Pipet
- Kağıt bardak 5 TL
- El işi kağıdı
- Plastik veya kağıt tabak 5 TL
- Oyun hamuru 10 TL
- Plastik şeffaf dosya
- Paket lastiği
- Aluinyum folyo 10 TL
- Strafor köpük
- Cam yünü
- Çöp şiş 5 TL
- Şişe kapağı 5 TL
- Strafor 5 TL

Problemi belirleme

Çözüm getireceğiniz problemi yazınız.

Şuan da var olan çözümler hangi açılardan yetersiz

Problemi araştırma

Bu problemi çözmek için hangi bilgilere ihtiyacınız var?

İhtiyacınız olan bilgilere nasıl ulaşabilirsiniz?

Tasarımınızın başarılı olması için gereken kısıtlamalar ve kriterler varsa nelerdir?

Kısıtlamalar	Kriterler

Başarılı bir çözüme gitmek için üzerinde durulması gereken tüm anahtar bilgileri yazınız.

Olası çözümler üzerine beyin fırtınası yapma

Uygun olabilecek tüm çözüm önerilerinizi yazınız.

Uygulanabilir gözükmese de öne çıkan tüm fikirleri listeleyin.

En iyi çözüme karar verme

Tüm olası çözüm önerileri için aşağıdaki tabloyu doldurun

Tabloya göre takım olarak kararınızı verin. Hangi çözüm sınırlılık ve kriterlerinizi en iyi şekilde karşılıyor

Kısıtlamalar	Tasarım 1	Tasarım 2

Basari Kriterleri	Tasarım 1	Tasarım 2

Seçtiğiniz çözümü açıklayınız. Nasıl karar verdiniz? Optimizasyon sürecini açıklayınız

Neden seçtiğiniz çözüm diğer çözüm önerilerinden üstün

Bir prototip Model geliştirin

Tasarımınızı çiziniz

Prototipi malzemelerle inşa ediniz

Test etme ve değerlendirme

İnşa ettiğiniz prototipi test alanında test ediniz

Tasarımı geliştirme

Neler Yanlış gitmiş olabilir?

- Tekerlekler dönmedi
- Düz bir çizgide seyahat etmedi
- İstenen mesafeye ulaşamadı
- Tasarım veya yük rampadan fırladı

- Güçlendirmek için tasarımınızda nasıl değişiklikler yapacaksınız

Tasarımın yenilenmiş halini çiziniz

Ek etkinlik

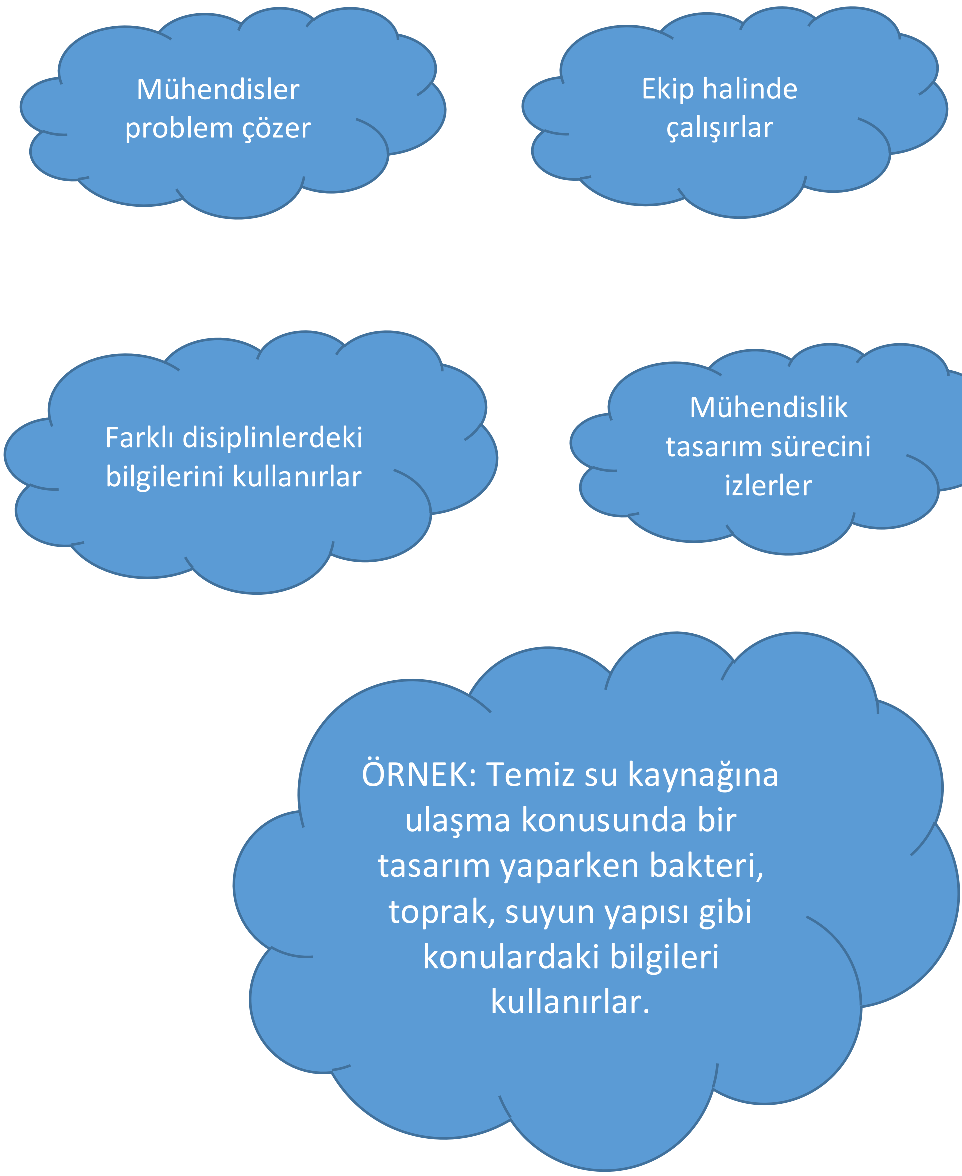
Veri Tablosu

Denemeler	Kullanılan yüzey	Aracın aldığı yol	Süre
1			
2			
3			
Ortalama			

MÜHENDİSLİĞİN DOĞASI

Mühendisler farkli çözüm önerileri üzerinde calisirlar. Daha sonra en uygun çözüm önerisi belirlenir. Tum cozum önerileri tum kriterleri karşılamayabilir. Ödün vermek seklinde ilerleyerek probleme cozum getirecek olan çözüm seçilir ve test edilir.

Farklı alanlarda uzman mühendisler birlikte çalışırlar



APPENDIX H

"SCIENCE TEACHERS'ATTITUDES TOWARDS K-12 ENGINEERING EDUCATION SURVEY" USED IN COGNITIVE INTERVIEWS

Ölcek maddeleri	**Tamamen katılmıyorum**	**Katılmıyorum**	**Kararsızım**	**Katılıyorum**	**Tamamen Katılıyorum**
1."Mühendislik ve tasarım eğitimi" konusunda hizmet içi egitimlere katılmak ilgimi çeker.					
2. Mühendislik tasarım etkinliklerini uygulamamiz, öğrencilerin fen, matematik, teknoloji ve mühendislik alanlarındaki mesleklere karsi ilgilerini artirir.					
3.Mühendislik tasarım uygulamaları konulu kaynakları (kitap, dergi, görsel materyaller gibi) incelemek isterim.					
4."Mühendislik ve tasarım eğitimi" konusunda kendimi gelistirmek beni heyecanlandırır.					
5.Mühendislik tasarım uygulamalarının öğrencilerin işbirlikli calışma becerilerini geliştireceğini düşünüyorum.					
6. Mühendislik uygulamalarının öğretim programlarına dahil edilmesinin toplumumuzu pozitif yönde etkiler.					
7.Örnek alabileceğim mühendislik tasarım etkinliklerini araştırmaktan keyif alırım.					
8."Mühendislik ve tasarım eğitimi" öğrencilerin iletişim becerilerini geliştireceğini düşünüyorum.					
9.Mühendislik tasarim etkinliklerinin okullarda uygulanması, toplumların karşı karşıya oldukları sorunların çözümüne katkı sağlar.					

10.Ögrencilerime mühendislik tasarım sürecini öğretme konusunda hevesliyim.					
11.‘Mühendislik ve tasarım etkinliği’ konusunda öğretmenlere yönelik eğitimleri ve seminerleri araştırmak ilgimi çekiyor.					
12. Okullarda mühendislik tasarim etkinliklerinin uygulanması toplum gelişimine katki sunacaktır.					
13..“Mühendislik ve tasarım eğitimi” öğrencilerin yaratıcı düşünme becerilerini geliştirebilmeleri açısından önemlidir.					
14.Okul yönetimim tarafından bir mühendislik tasarım etkinliği hazırlamam istendiğinde, verilen görevin başka bir öğretmene verilmesini rica edebilirim.					
	Tamamen katılmıyorum	**Katılmıyorum**	**Kararsızım**	**Katılıyorum**	**Tamamen Katılıyorum**
15.Öğrencilerim için mühendislik tasarim etkinlikleri hazirlarken, az malzeme ve zaman gerektiren etkinlikleri secerim.					
16.Öğretmenlere yönelik ‘mühendislik ve tasarım eğitimi’ konulu bir seminere yalnızca katılım sertifikası alabilmek için katılırım.					
17. Mühendislik uygulamalarının öğretim programlarına dahil edilmesinin öğrenciler açısından olumlu olacağını düşünüyorum.					
18.‘Mühendislik ve tasarım eğitimi’ öğrencilerin farkli disiplinlerin birbiriyle nasıl ilişki içerisinde olduklarını anlamalarina katki sağlar.					
19.Mühendislik tasarım etkinliklerini yalnızca zorunlu durumlarda uygularim.					
20. Mühendisliğin öğretim programlarına dahil edilmesi ile öğrencilerin girisimcilik becerileri gelişir.					
21. “Mühendislik ve tasarım eğitimi”, öğrencilerin varolan bilgileri ürüne dönüştürmesi acısından değerlidir.					
22.Ders saatlerinden sonra mühendislik tasarım etkinliklerinin uygulanacagı bir öğrenci klübü oluşturmak ilgimi çeker.					
23.Öğrencilerin temel bir mühendislik kavrayışına sahip olmalarını önemli buluyorum					

APPENDIX I

FINAL VERSION OF THE "SCIENCE TEACHERS'ATTITUDES TOWARDS K-12 ENGINEERING EDUCATION SURVEY"

Ölçek maddeleri- Birinci Bölüm	Tamamen katılmıyorum	Katılmıyorum	Kararsızım	Katılıyorum	Tamamen Katılıyorum
1. Derslerime mühendislik tasarım sürecinin dahil edilmesi konusunda kendimi mesleki olarak geliştirebileceğim eğitimlere ve seminerlere katılmak ilgimi çeker.					
2.Öğrencilerime mühendisliğe temel oluşturan fen kavramlarını öğretme konusunda kendimi mesleki olarak geliştirmek isterim.					
3. Fen eğitiminde mühendislik tasarım uygulamaları konulu kaynaklar (kitap, dergi, video, görsel materyaller gibi) ilgimi çeker.					
4. Sınıfımda yenilikçi mühendislik tasarım etkinlikleri hazırlamaya ve uygulamaya istekliyim.					
5.Mühendislik tasarım etkinliklerinin öğrencilerin takım çalışması becerilerini geliştireceğini düşünüyorum.					
6. Çalışma arkadaşlarım ile mühendislik tasarım uygulama deneyimlerimizi paylaşmaya istekliyim.					
7. Örnek alabileceğim mühendislik tasarım etkinliklerini araştırmaktan keyif alırım.					
8.Öğrencilerin mühendislik ve tasarım becerilerinin gelişmesini önemli buluyorum.					
9. Okul öncesinden başlayarak 12. sınıfa kadar öğretim programlarında mühendislik uygulamalarına yer verilmesi gerektiğine inanıyorum.					

10.Öğrencilerime mühendislik tasarım sürecini öğretme konusunda hevesliyim.					
11. Fen öğretim programına mühendislik tasarımın dahil edilmesinin önemli olduğunu düşünüyorum.					
12. Mühendislik tasarım etkinlikleri, öğrencilerin yaratıcı düşünme becerilerini geliştirebilmeleri açısından önemlidir.					
13. Okul yönetimim tarafından bir mühendislik tasarım etkinliği hazırlamam istenirse, verilen görevi yapmaktan kaçınırım.					
	Tamamen katılmıyorum	**Katılmıyorum**	**Kararsızım**	**Katılıyorum**	**Tamamen Katılıyorum**
14.Öğretmenlere yönelik mühendislik tasarım uygulamaları konulu bir seminere katılım sertifikası alabilmek için katılırım.					
15. Mühendisliğin fen eğitimine entegrasyonu fen konularını öğrenciler için daha ilgi çekici hale getirecektir.					
16. Öğrencilerime mühendislik tasarım sürecini öğretmek için becerilerimi geliştirmeye istekliyim.					
17. Mühendislik tasarım uygulamalarının öğretim programlarında yer alması toplumsal sorunların çözümüne katkı sağlar.					
18.Mühendislik tasarım etkinliklerini yalnızca zorunlu durumlarda uygularım.					
19. Okul öncesinden başlayarak 12. sınıfa kadar mühendislik tasarım etkinliklerinin uygulanması ile öğrencilerin yenilikçi düşünme becerileri (inovasyon) gelişir.					
20. Mühendislik tasarım etkinlikleri, öğrencilerin var olan bilgileri ürüne dönüştürmesi açısından değerlidir.					
21.Ders saatlerinden sonra mühendislik tasarım etkinliklerinin uygulanacağı bir öğrenci kulübü oluşturmak ilgimi çeker.					

22.Öğrencilerimin problemlere bir mühendis gibi yaklaşmalarını önemli buluyorum.					
23. Öğrencilerime sınıfta tasarım yaparlarken destekleme noktasında yeterli donanımım olduğuna inanıyorum.					
24. Sınıfta mühendislik tasarım etkinlikleri uygulamak bana heyecan veriyor.					

Ölçek maddeleri- İkinci Bölüm

25.mühendislik tasarım süreci uygulamarı konulu kaynakları

a. İncelemek istemem

b. Zorunda olursam incelerim

c. Kararsızım

d. Hızlıca bakmak isterim

e. İncelemekten keyif alırım

26. Fen eğitimine mühendisliğin entegrayonu konulu bir öğretmen eğitimine katıldığımda

a. Etkinliklere katılımda gönülsüz olabilirim

b. Katılım sertifikası almak için katılırım

c. Kararsızım

d. Etkinliklere aktif olarak katılmak isterim

e. Öğrenmeye istekliyim ve kendimi geliştirmek beni heyecanlandırır

27. Sınfınızda uygulamak üzere bir mühendislik tasarım etkinliği hazırlamam istendiğinde

a. Isteksiz olurum

b. Daha önce uygulanmış bir etkinliği olduğu gibi uygularım

c. Biraz araştırma yaparak bir etkinlik hazırlarım

d. İyi bir araştırma ile bir etkinlik hazırlarım

28. Sınıfiçi bir mühendislik tasarım etkinliği uygulamak

a. Fazla ilgimi çekmez

b. İlgimi çekebilir

c. Bazen beni heyecanlandırır

d. Her zaman beni heyecanlandırır

APPENDIX J

INFORMED CONSENT FORM

Gönüllü Katılım Formu

Bu çalışma ODTÜ Eğitim Bilimleri Bölümünde, Yrd. Doç. Dr. Evrim Baran danışmanlığında araştırma görevlisi Canan Mesutoğlu tarafından yürütülen araştırma çalışmasıdır. Çalışmanın amacı, a) fen öğretmenlerinin mühendislik ve tasarım eğitimine karşı tutumlarınını temsil edecek bir öğrenme ilerlemesi (learning progression) tasarlamak ve veri toplama aracı geliştirmek, b) geliştirilen öğrenme ilerlemesi ve mühendislik ve tasarım eğitimi konusunda verilecek eğitimler ile öğretmen tutumlarındaki gelişimi takip etmek, ve c) mühendislik ve tasarım eğitimi konusunda verilecek eğitimlerin fen öğretmenlerinin etkinlik tasarlama ve uygulamalarını hangi yönlerde gelistirdiğini ortaya koymaktır.

Çalışmaya katılım tamamıyla gönüllülük temelindedir. Veri toplama araçlarında, sizden kimliğinizi belirleyici hiçbir bilgi istenmemektedir. Cevaplarınız tamamen gizli tutulacak ve sadece araştırmacılar tarafından değerlendirilecektir. Elde edilecek bilgiler sadece bilimsel amaçlı kullanılacaktır. Sorular kişisel rahatsızlık verecek içerik içermemektedir. Ancak, soruları cevaplarken sorulardan ya da herhangi başka bir nedenden ötürü kendinizi rahatsız hissederseniz yarıda bırakmada serbestsiniz. Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz. Çalışma hakkında daha fazla bilgi almak için Araştırma Görevlisi Canan Mesutoglu (Tel: (312) 210 4046; e-posta: mcanan@metu.edu.tr) ile iletişim kurabilirsiniz.

Bu çalışmaya tamamen gönüllü olarak katılıyorum ve istediğim zaman yarıda kesip bırakabileceğimi biliyorum. Verdiğim bilgilerin bilimsel amaçlı yayımlarda kullanılmasını kabul ediyorum. (Forma onay verdikten sonra soruları cevaplayınız).

APPENDIX K

VITA

Canan Mesutoğlu, Ph.D.

E-mail: canan.mesutoglu@gmail.com

EDUCATION

Ph.D. 2017, Middle East Technical University, Ankara, Turkey
Major: Curriculum and Instruction
Advisor: Dr. Evrim Baran
Dissertation Title: Developing Teacher Learning Progressions For K-12 Engineering Education: Teachers' Attitudes And Their Understanding of the Engineering Design

M.S. 2012, Middle East Technical University, Ankara, Turkey
Major: Guidance and Psychological Counseling
Advisor: Dr. Ayhan Demir
Thesis Title: The Relationship among Self Construal, Family Functioning and Sibling Number in Terms Of Gender in High School Students

B.S. 2007, Bogazici University, Istanbul, Turkey
Major: Elementary Science Education
Certified as an elementary science teacher

PROFESSIONAL EXPERIENCE

Fulbright Visiting Ph.D. Student & Researcher, 08/2015 - 06/2016
University of California, Berkeley, Graduate School of Education, CA, U.S.
Research Topic: Developing construct maps and learning progressions

Research Assistant, 11/2009 - Present
Department of Educational Sciences, Middle East Technical University, Ankara, Turkey

Science Teacher, 08/2007 - 06/2009
Eyuboğlu Educational Institution, Istanbul, Turkey

Voluntary Specialist, 09/2013 - 05/2015

Flying Broom (Uçan Süpürge) Women Communication and Research Association, Ankara, Turkey

English Translator, 07/2012 - Present

Merkur Import and Export Limited Company, Istanbul, Turkey (working freelance)

Undergraduate Research Assistant, 09/2006 - 06/2007

Laboratory Applications in Science Education Undergraduate Course, Bogazici University, Istanbul, Turkey

Guide for Science Activities, 09/2006 - 06/2007

Nezahat Gökyiğit Botanical Garden, Istanbul, Turkey

PROJECTS

Mesutoğlu, C., Baran, E., & Çakıroğlu, E. (2017). Co-Principle Investigator. Design, Make, Learn: Professional development program for middle school science teachers on engineering design. Middle East Technical University, Ankara, Turkey. Supported by BILTEMM (Center for Science, Technology, Engineering, and Mathematic Education) and METUWIND, Middle East Technical University https://tasarlayapogren.wordpress.com

Karahan, E., Canbazoğlu-Bilici, S. & Baran, E. (2017). Guide. Professional science teacher development program on problem based STEM (Science, Technology, Engineering, Mathematics) Education. Osmangazi University, Eskisehir, Turkey. Funded by The Scientific and Technological Research Council of Turkish Research Council, http://www.pdstemuygulamalari.com

Çakiroğlu, E. & Baran, E. (2016). Instructor. Professional teacher development program on STEM Education. Supported by BILTEMM, Middle East Technical University, Ankara, Turkey, http://sem.metu.edu.tr/egitim_pdf/stem2.pdf, https://biltemm.metu.edu.tr/en/projects

Wilson, M. (2016). Researcher. San Francisco Health Investigators (SF HI). Developed and led by the Science & Health Education Partnership at UC San Francisco, U.S.

Baran, E., Cakıroğlu, E. & Canbazoğlu-Bilici, S. (2015). Trainer and guide. Young inventors designing the future: Science, Technology, Engineering and Mathematics (STEM) Education, Middle East Technical University, Ankara. Funded by The Scientific and Technological Research Council of Turkish Research Council https://fetemmodtu.wordpress.com/

Canbazoğlu-Bilici, S., Baran, E. & Yamak, H. (2014). Guide. Educational applications for science teachers on technological pedagogical content knowledge

(TPACK) Project. Funded by The Scientific and Technological Research Council of Turkish Research Council, http://www.tpabuygulamalari.com

Flying Broom (Uçan Süpürge) Women Communication and Research Association. (2013-2015). Researcher. My Madame Curie: The stories of four women scientists into making an animated movie for 4th grade students, Turkey. Funded by Turkish Ministry of National Education. http://festival.ucansupurge.org/EN,2600/my-madame-curiem.html

Erentay, N. (2015). Jury member. Science on Stage Europe: Science on Stage Festival 2015, Middle East Technical University, Ankara, http://www.science-on-stage.eu/page/display/2/2/185/tr/turkey

PUBLICATIONS

Baran, E., Canbazoğlu-Bilici, S., Mesutoğlu, C. & Ocak, C. (2016). Moving STEM beyond schools: Students' perceptions about an out-of-school STEM education program. *International Journal of Education in Mathematics, Science and Technology, 4*(1), 9–19.

Baran, E., Canbazoğlu-Bilici, S. & Mesutoğlu, C. (2015). Science, technology, engineering, and mathematics (STEM) public service announcement (PSA) development activity [Fen, teknoloji, mühendislik ve matematik (FeTeMM) spotu geliştirme etkinliği] *Journal of Inquiry Based Activities* [*Araştırma Temelli Etkinlik Dergisi*], *5*(2), 60–69.

CONFERENCE ACTIVITIES

Baran, E. & Mesutoğlu, C. (2015). *A systematic review of the literature on learning progressions in science education: Developing critical elements.* American Educational Research Association (AERA) 2015 Annual Meeting, Chicago, IL, USA, April 16 – 20, 2015.

Mesutoğlu, C. & Birgili, B. (2015). *Targeting misconceptions in teacher education: Views and practices of pre-service science and mathematics teachers.* VII. International Congress of Educational Research, Muğla Sıtkı Koçman University, Turkey, May 29-31, 2015.

Mesutoğlu, C. (2014). *Improving the professional development of pre-service science teachers and raising little scientists.* 11th National Science and Mathematics Education Congress, Çukurova University, Adana, Turkey, September 11-14, 2014.

Mesutoğlu, C. (2014). *Views of science teachers and academicians on the 2013 Sciences Curriculum for the 5th grade.* 11th National Science and Mathematics Education Congress, Çukurova University, Adana, Turkey, September 11-14, 2014.

Somuncuoğlu, S. & Mesutoğlu, C. (2014). *Transferring the women who enlightened our path to young generations: An exemplary project "My Madame Curie".* Writing Women's Lives International Symposium, Yeditepe University, Istanbul, Turkey, April 19-20, 2014.

PARTICIPATION AT WORKSHOPS, PANELS AND SYMPOSIUMS

(2016) STEAM Symposium: Innovative Methods to Enhance Careers in STEAM Education: Science, Technology, Engineering, Arts, and Mathematics, 2016, University of California, Berkeley, U.S.

(2016) The Expanding Potential in STEM Fields Workshop, January 30-31, 2016, University of California, Berkeley, U.S.

(2015) Science leadership and management (SLAM) weekly workshop series. September 14-December 14, 2015, University of California, Berkeley, U.S.

(2015) Fulbright minds: Building the pipeline of girls and women in STEM Panel Series. Institute of International Education, November 17, 2015, San Francisco, U.S.

MEMBERSHIPS

Fulbright Alumni, Toastmasters, University of California, Berkeley, CA, U.S.

TEACHING EXPERIENCES

Middle East Technical University, Ankara, Turkey

Graduate Courses

Research Methods in Education, Fundamentals of Learning Sciences

Undergraduate Courses

Classroom Management, Educational Statistics

SERVICE

(2016) Volunteer. Lawrence Hall of Science, University of California, Berkeley, CA, U.S.

(2015) Volunteer. BASIS (Bay Area Scientists in Schools), Berkeley, CA, U.S.

APPENDIX L

APPROVAL FROM METU ETHICS COMMITTEE

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
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05 ARALIK 2016

Konu: Değerlendirme Sonucu

Gönderilen: Yrd. Doç.Dr. Evrim BARAN

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Yrd. Doç.Dr. Evrim BARAN;

Danışmanlığını yaptığınız doktora öğrencisi Canan MESUTOĞLU' nun "Fen Öğretmenin Mühendislik ve Tasarım Eğitimi Konusunda Tutum ve Uygulamalarının Öğrenme İlerlemesi Yöntemi ile Ortaya Konması ve İzlenmesi" başlıklı araştırması İnsan Araştırmaları Kurulu tarafından uygun görülerek gerekli onay **2016-EGT-168** protokol numarası ile **05.12.2016-01.09.2017** tarihleri arasında geçerli olmak üzere verilmiştir.

Bilgilerinize saygılarımla sunarım.

Prof. Dr. Canan SÜMER
İnsan Araştırmaları Etik Kurulu Başkanı

Prof. Dr. Mehmet UTKU
İAEK Üyesi

Prof. Dr. Ayhan SOL
İAEK Üyesi

Prof. Dr. Ayhan Gürbüz DEMİR
İAEK Üyesi

Doç. Dr. Yaşar KONDAKÇI
İAEK Üyesi

Yrd. Doç. Dr. Pınar KAYGAN
İAEK Üyesi

Yrd. Doç. Dr. Emre SELÇUK
İAEK Üyesi

APPENDIX M

TURKISH SUMMARY / TÜRKÇE ÖZET

Giriş

Son yıllarda fen, teknoloji, mühendislik, ve matematik (FeTeMM) alanlarına anaokulundan 12. Sınıfa kadar tüm eğitim düzeylerinde önem verildiği görülmektedir (Capobianco & Rupp, 2014; Honey, Pearson, & Schweingruber, 2014; National Research Council (NRC), 2009). Problemlere alternatif bakış açılarını değerlendirerek yaklaşan, sistematik ve yaratıcı düşünebilen ve ürünler sunarak çözüm üreten öğrencilerin yetişebilmesi için FeTeMM eğitimi ön palana çıkmaktadır (MoNE, 2016). FeTeMM alanlarında öğrencilerin yetişmesini sağlamak (Page, Lewis, Autenrieth, & Butler-Purry, 2013) ve toplum gelişimi için FeTeMM eğitimine yönelimi artırmak (National Science Board, 2010) son derece önemlidir. 21. Yüzyılda ülkelerin başarılı olmaları ve rekabet edebilmeleri için FeTeMM alanlarında yetişen kişilere ihtiyacı vardır (Çorlu, Capraro & Capraro, 2014). FeTeMM pedagojisi inovasyon, yaratıcı düşünme, işbirlikli çalışma ve eleştirel düşünme gibi 21. Yüzyıl becerilerinin gelişmesini sağlar (NRC, 2012; Perry vd., 2008). Bu becerilerin gelişmesi için bu yaklaşımda fen ve mühendislik becerileri öne çıkmaktadır (NGSS Lead States, 2013). Mühendislik eğitimi, FeTeMM disiplinlerinin kavramsal olarak anlaşılması, mühendisliğe karşı ilgi oluşturma ve mühendislerin toplum ilerlemesindeki rollerinin anlaşılması noktalarında büyük potansiyele sahiptir (Brophy, Klein, Portsmore, & Rogers, 2008). Anaokulundan 12. Sınıfa kadar tüm eğitim düzeylerinde mühendisliğin öğretime entegrasyonunda öğretmenlerin önemli rolü bulunmaktadır. (Hsu, Cardella, & Purzer, 2010). Bu anlamda fen dersini mühendislik pratikleri ile öğretebilecek öğretmenlere ihtiyaç bulunmaktadır

(Capobianco & Rupp, 2014; Guzey, Moore & Morse, 2016). Öğrenciler disiplinlere ait kavramları öğrenirken fen ve mühendislik disiplinlerini beraber kullanmaları önemlidir. Tüm seviyelerde mühendisliğe vurgu yapılması öğrenme, akademik başarı, mühendisliğin doğasını anlama ve mühendislik ile teknoloji alanlarına ilgiyi artırma anlamında kritiktir (NRC, 2009).

Mühendisliğin fen öğretimine entegrasyonu öğretmenler için yabancı pedagojik yaklaşım ve pratiği beraberinde getirmektedir; mühendislik tasarım süreci, ve modelleme gibi (Yoon, Diefes-Dux, & Strobel, 2013). Fen öğretmenlerinin fen öğretiminde mühendislik tasarım sürecini kullanabilmeleri için gerekli bilgi ve beceriye sahip olmaları gerekmektedir (Capobianco, & Rupp, 2014), ancak öğretmen eğitimindeki eksiklikler mühendisliğin yeterince vurgulanmasını engelleyen bariyerlerden birisidir (Fadali & Robinson, 2000). Öğretmenlerin yeni konularda bilgi ve becerilerini geliştirmeleri yüksek kaliteye sahip öğretmen gelişimi programları ile mümkün olabilmektedir (Capobianco & Rupp, 2014). Öğretmenlerin sınıf içi pratiklerinin iyileşmesi ve öğrencilere olumlu yansımaları olması açısından öğretmen profesyonel gelişim programları önemlidir (Supovitz & Turner, 2000; Yoon, Diefes-Dux, & Strobel, 2013). Öğretmenlerin mühendislik eğitimine karşı olumlu tutumlarının ve kavrayışlarının sınıf içi pratiği etkileyeceğinden, öğretmenlerin hem tutum hem anlayışlarının gelişmesi vurgulanmalıdır.

Öğretmenlerin mühendisliğin fen eğitimine entegrasyonuna karşı tutumlarının ve mühendislik tasarım süreci kavrayışlarının gelişmesi için profesyonel gelişim programlarına katılmaları önem taşımaktadır. Çalışma kapsamında fen öğretmenlerine yönelik bir öğretmen eğitimi tasarlanmış ve uygulanmıştır. Bu eğitim ile fen öğretmenlerinin mühendislik pratikleri gibi yeni bir alanda gelişmeleri hedeflenmiş ve aynı zamanda geliştirilen öğrenme ilerlemelerine yönelik ampirik veri toplanarak iyileştirmeler sağlanmıştır. Öğretmen eğitimi programının kavramsal temelini oluşturmak için ilgili alan yazın dikkatlice taranmıştır. Bu doğrultuda ulaşılan 21 tane mühendislik eğitimi konusunda verilen öğretmen eğitimleri konulu çalışma, analitik bir tabloya dökülerek farklı açılardan irdelenmiştir. Ardından mühendisliğin üniversite öncesi seviyelerde eğitime entegrasyonunu konu alacak bir öğretmen eğitiminde bulunması gereken esas nitelikler belirlenmiştir. Bu nitelikler şu şekilde sıralanmıştır, gerçek yaşam temalı mühendislik tasarım etkinlikleri, alan gezileri, mühendislerle işbirliği içinde çalışma, öğretmenleri tasarım takımları oluşturması, yüzyüze çalıştay sonrası sınıf içi uygulamalar, tematik çerçeve, ve mühendislik doğasına uygun bilgi aktarımı. Bu esas niteliklerden sınıf içi uygulamalar hariç hepsi çalışma kapsamında uygulanan öğretmen eğitiminde karşılanmıştır.

Eğitimde yeni yaklaşımların başarılı olmasında öğretmenlerin tutumları önemli bir yere sahiptir; yapılandırmacı öğrenme etkinlikleri (Kasapoğlu, 2010), mobil uygulamaların kullanımı (Zyad, 2016) gibi. Öğretmenlerin olumsuz tutumları mühendislik pratiklerinin entegrasyonunda bariyer teşkil edebilir. O nedenle öğretmen tutumlarını ortaya koymak önemlidir (Yoon vd., 2013). Öğretmenlerin mühendislik tasarımı ile ilgili deneyim kazanmaları, hem mühendislik entegrasyonuna karşı hem de FeTeMM eğitimine karşı olan tutumlarını etkileyebilir (Nadelson vd., 2013). Öğretmenlerin mühendislik tasarım sürecini anlamlandırmaları, mühendisliğin fen öğretimine entegrasyonunda başarılı olunması için önemli bir diğer noktadır. Henüz fen öğretiminde mühendislik tasarım sürecinin kullanılması yaygınlık kazanmamıştır (Guzey, Tank, Wang, Roehrig, & Moore, 2014). Öğretmenlerin genellikle mühendislik uygulamaları ile ilgili bir deneyime sahip olmadıkları gözlemlenmiştir (Lehman, Kim, & Harris, 2014). Öğretmenlerin mühendislik tasarım süreci ile ilgili bilgi ve beceri kazanmaları ve olumlu tutum geliştirmeleri için öğretmenlere yönelik profesyonel gelişim programları etkilidir.

Öğretmenlerin eğitimde mühendislik uygulamaları konusunda gelişimini ölçecek araçların sayısı oldukça azdır (Lachapelle, Hertel, Shams, San Antonio, & Cunningham, 2014; Yaşar, Baker, Robinson-Kurpius, Krause, & Roberts, 2006). Ancak öğretmenlerin gelişimini ölçmek ve takibini yapmak, öğretmen mühendislik uygulamalarında profesyonel gelişimlerini sağlaman için önemli geri bildirimler sağlayacaktır. Mühendisliğin fen öğretimine entegrasyonu oldukça yeni bir yaklaşım olduğu için, öğretmenlerin tutumları ve mühendislik tasarım süreci noktasındaki kavrayışlarını ölçmek ve ortaya koymak önem taşımaktadır. Öğretmenlerin tutumlarını ve mühendislik tasarım süreci kavrayışlarını ölçmek ve takibini yapmak için araçlar geliştirilmesi öğrenme ilerlemeleri (learning progressions) yaklaşımının kullanılmasını gerekli kılmaktadır.

Öğrenme ilerlemeleri fen eğitimine yeni bir bakış açısı sunmaktadır (Duncan & Hmelo-Silver, 2009, Salinas, 2009). Öğrenme ilerlemeleri, anlamlı ölçme ve değerlendirme araçlarının geliştirilmesi için hizaya dizilmiş seviyeler üzerinden sistematik bir çerçeve sunmaktadır (Alonzo & Steedle, 2009). Öğrenme ilerlemeleri "gittikçe karmaşıklaşan ve derinlik kazanan anlayış ve düşünüş biçimlerini" ortaya koymaktadır (Duschl, Maeng, & Sezen, 2011, s. 131). Öğrenen konumundaki kişinin kuram ve ampirik bulgular üzerinden inşa edilen seviyelerde ilerlemesi odak noktasıdır. Bu ilerleme daha düşük seviye bir anlayış, kavrayıştan daha yüksek seviye yani daha karmaşık bir anlayış, kavrayışa doğru olabileceği gibi (Plummer & Krajcik, 2010; Songer, Kelcey, & Gotwals, 2009), tutum gibi psikolojik bir değişken smz konusuysa, düşük dereceden yüksek seviyeye doğru olabilir (Mahat, 2008; Nguyen & Griffin, 2013). Öğrenme ilerlemeleri geliştirilirken, ölçme araçları geliştirerek veya veya öğretim ortamları tasarlayarak öğrenme ilerlemeleri seviyelerinin doğrulanması sağlanır (Duncan & Hmelo-Silver, 2009; Wilson, 2005). Öğrenme ilerlemeleri ortaya koyduğu seviyeler ile daha sağlıklı ve güvenilir geri bildirim verilebilmesini kolaylaştırmaktadır.

Öğrenme ilerlemeleri güncel olarak sıklıkla öğrenciler için geliştiriliyor olsa da (Alonzo & Steedle, 2009; Shea & Duncan, 2013), öğretmenlerin bilgi ve pratiklerinin ilerlemesinin izlenmesi amacı ile de geliştirildiği görülmüştür (Nguyen & Griffin, 2012; Jin, Shin, Johnson, Kim, & Anderson, 2015; Windschitl, Thompson, Braaten, & Stroupe, 2012). Öğretmenlerin ilerleme ve gelişimlerinin, mühendislik eğitiminde tutum ve kavrayışları odağı ile ortaya konarak, öğretmen gelişimi alan yazınına katkı sunmak hedeflenmiştir. Öğrenme ilerlemeleri uygulanan profesyonel öğretmen eğitimi programı ile test edilmiş ve iyileştirmeler sağlanmıştır.

Çalışmanın Amacı ve Araştırma Soruları

Çalışma, fen öğretmenlerinin tutum ve mühendislik tasarım süreci kavrayışları üzerine öğrenme ilerlemeleri geliştirmeyi hedeflemiştir. Mühendislik kavram ve pratiklerinin fen eğitimine entegrasyonu noktasında öğretmenlerin hem tutumları hem de mühendislik tasarım süreci hakkındaki bilgi ve anlayışları etkili olacaktır. Çalışmanın iki ana amacı şu şekilde sıralanmıştır: a) ortaokul fen öğretmenlerinin mühendisliğin fen eğitimine entegrasyonuna karşı tutumları üzerine öğrenme ilerlemesi geliştirmek, b) ortaokul fen öğretmenlerinin mühendislik tasarım süreci hakkındaki kavrayışları üzerine öğrenme ilerlemesi geliştirmek. Çalışmanın ilk amacını karşılamak için, ve öğrenme ilerlemesinin ampirik doğrulamasının yapılması için bir ölçek geliştirilmiştir. Ayrıca özellikle ikinci amaca hizmet etmek ve öğrenme ilerlemesinin ampirik doğrulamasını sağlamak için bir öğretmen eğitimi düzenlenip uygulanmıştır. Çalışmaya yön veren araştırma soruları aşağıda verilmiştir:

5. Ortaokul fen öğretmenlerinin mühendisliğin fen eğitimine entegrasyonuna karşı tutumları bir öğrenme ilerlemesi ile nasıl ortaya konabilir?

    1.a. Öğrenme ilerlemesinin ampirik doğrulamasının yapılması için öğretmenlerin tutumlarını ortaya koyacak bir ölçek nasıl ortaya konabilir?

6. Ortaokul fen öğretmenleri mühendislik tasarım sürecini kavrama noktasında daha düşük seviye bir kavrayıştan, yüksek bir kavrayışa doğru hangi seviyelerden geçerek ilerlerler?

Araştırmanın Önemi

FeTeMM eğitimi üzerine önemli kaynaklardan "STEM 2026" raporunda (U. S. Department of Education, 2016) altı adet birbirine bağlı bileşenden bahsedilmektedir. Bu bileşenlerde üç tanesi, bu çalışmanın amaçları ile doğrudan işaret edilmektedir: a) riske ve deneme içiren eğitim aktivitelerinin sağlanması, b) zorlu görevlerin çözümlenmesine dayanan öğrenme deneyimlerinin sağlanması, ve c) öğrenmenin yenilikçi ve ulaşılabilir ölçümlerinin sağlanması. Bu bileşenlerden ilk ikisine çalışma kapsamında öğretmenlere sağlanan öğretmen eğitimi programı ile gerçekleştirilen etkinliklerde işaret edilmiştir. Üçüncü bileşen noktasında da, geliştirilen öğrenme ilerlemeleri, öğretmenlerin tutum ve kavrayışlarını sistematik olarak ortaya koyma çabası ile vurgulanmıştır.

Öğrenme ilerlemeleri üzerine alan yazın çoğunlukla üniversite öncesi çeşitli seviyelerden öğrencilerin ölçümüne ve gelişimine odaklanmıştır. Ancak öğretmenlerin gelişimlerinin izlenmesi ve gerekli geri bildirim verilmesi amacı ile yeni geliştirilen örnekler bulunmaktadır (Furtak, Thompson, Braaten, & Windschitl, 2012; Jin vd., 2015). Öğretmenlerin gelişimlerinin sağlanması öğrenme ilerlemelerinin ana amaçları arasındadır (Kobrin, Larson, Cromwell, & Garza, 2015). Öğrenciler için mühendislik becerileri üzerine öğrenme ilerlemesi bulunmaktadır (Berland & McNeill, 2010), ancak çalışmanın sunduğu mühendislik tasarım süreci öğrenme ilerlemesi alan yazın için öncü niteliktedir. Öğrenme ilerlemelerini öğretmen gelişimi için kullanmak ve öğretmenlerin tutum ve mühendislik tasarım kavrayışlarına odaklanmak alan yazına yenilik katmaktadır.

Öğrenme ilerlemelerinin hem teorik hem de ampirik bulgular ile desteklenerek geliştirilmesi diğer ölçme yöntemlerine yenilikçi bir bakış sunmaktadır (Wilson, 2005). Özellikle ara seviyelerin ortaya konması ilerlemenin izlenmesi ve değerlendirilmesi noktasında oldukça değerlidir (Gotwals & Songer, 2013).

Ortaokul seviyesi fen eğitimine mühendislik kavram ve yöntemlerinin entegrasyonu, öğretmenlerin yeterlikleri ve profesyonel gelişimlerini gündeme getirmektedir (Brophy vd., 2008). Mühendisliğin fen eğitimine dahil olması öğretmenlere yönelik nitelikli profesyonel gelişim programlarını gerekli kılmaktadır (Guzey et al., 2014). Öğretmenlerin mühendislik tasarım süreci üzerine çalıştıkları daha fazla sayıda profesyonel gelişim programları düzenlenmelidir (Donna, 2012; Hynes & Santos, 2007). Mühendisliğin üniversite öncesi seviyelerde eğitime entegrasyonunun sağlanması açısından öğretmenlerin mühendislik kavramlarını anlamaları ve öğrencilerine mühendisli tasarım sürecini öğretirken rahat olmaları önemlidir (NRC, 2009).

Mühendislik eğitimine karşı öğretmenlerin tutumlarının gelişiminin, ve mühendislik tasarım süreci kavrayışlarının gelişim seviyelerinin ortaya konması, üniversite öncesi seviyelere mühendisliği entegre etme noktasında kolaylaştırıcı rol oynayacaktır. Bu noktada öğrenme ilerlemesi gibi Türkiye bağlamı için yenilikçi bir yöntem izlenmesinin ilham verici olacağı düşünülmektedir.

Alan Yazın Taraması

Bu çalışmanın alan yazın taramasında aşağıdaki başlıklar ele alınmıştır:

Mühendislik eğitiminin ortaya çıkışı

Türkiye bağlamında FeTeMM eğitimi ve mühendislik entegrasyonu

Öğretmenlerin mühendislik eğitimine karşı tutumları

Öğretmenlerin mühendislik tasarım süreci kavrayışları

Mühendislik entegrasyonu konusunda profesyonel öğretmen gelişim programları, ve

Öğrenme ilerlemeleri

Yöntem

Araştırma Deseni

Öğrenme ilerlemelerinin geliştirilmesi için tasarım-tabanlı araştırma yöntemi izlenmiştir (Collins, Joseph, & Bielaczyc, 2004). Tasarım-tabanlı araştırma deseni, “öğrenmenin gerçek bağlamında sistematik tasarım çerçevesinde yenilikçi bir yaklaşımdır” (The Design-Based Research Collective, 2003, s. 5). Bu yöntem, çeşitli eğitim pratikleri ve eğitim araçları üzerine çalışılırken kullanılmakta ve pek çok problem yanıt aramaktadır. Bu problemlerle ilgili şu ifade özetleyici niteliktedir: “laboratuvar ortamı yerine öğrenmenin kendi özgün ortamında çalışılmasına olan ihtiyaç, öğrenmeyi sığ ve kısıtlı bir şekilde ölçülmesi, ve biçimlendirici değerlendirme ile araştırma bulgularına ulaşmak” (Collins vd., 2004, p. 16).

Anderson ve Shattuck (2012)'a göre tasarım pratiği prototiplerin oluşturulması, test edilmesi ve yeniden düzenlenerek geliştirilmesi şeklinde birbirini tekrar eden döngülerle ilerler.

Çalışma özellikle üç açıdan tasarım-tabanlı araştırmanın özelliklerine vurgu yapmaktadır; ön araştırma yapılması, prototip geliştirilmesi, ve ölçme uygulaması (Van den Akker vd., 2006b). Sıralanan özellikler öğrenme ilerlemesi geliştirme sürecinin önceki alan yazın bulgularından faydalanması, ilk versiyonlarının veya prototiplerin geliştirilip daha sonra yeniden düzenlenmesi, ve sürekli bir revizyon sürecinin olması noktalarında üzerinde durduğu ilkelerdendir. Öğrenme ilerlemesi araştırmaları genellikle eğitim ortamlarında kullanılacak ve takip ve ölçme süreçlerine katkı sunacak araçların geliştirilmesini ve öğrenme ortamlarının veya materyallerinin sunulmasını içermektedir (Furtak, Thompson, Braaten, & Windschitl, 2012; Kobrin vd., 2015; Wilson, 2009). Tasarım-tabanlı araştırma deseninin sunduğu perspektif çalışma kapsamındaki öğrenme ilerlemelerinin, tutum ölçeğinin ve öğretmenler için profesyonel gelişim programının geliştirilmesine olanak sağlamaktadır (Hernández, Couso, & Pintó, 2015). Özellikle çalışma kapsamında takip edilen birden fazla veri toplama ve analiz döngüsü ve bu döngülerin sonucu olarak geliştirme ve iyileştirmelerin yapılması tasarım-tabanlı araştırma deseni ile uyum içerisindedir. Öğrenme ilerlemesi geliştirilen çalışmalar, benzer şekilde bu araştırma deseninden faydalanmaktadırlar (Jin vd., 2015; Stevens, Delgado, & Krajcik, 2010).

Araştırma çerçevesi üç başlıca evreden oluşmaktadır. Bu evreler döngüsel bir şekilde sıralanmıştır, yani ileride yapılacak araştırmalar aynı döngüyü tekrar edebilirler. Birinci evrede alan yazın bulgularına ve toplanan ön ampirik veri analiz sonuçlarına dayanarak öğrenme ilerlemeleri düşükten yükseğe seviyeleri içerecek şekilde tasarlanmıştır. Birinci evre sonunda tasarlanan bu öğrenme ilerlemeleri seviyelerinin yeni veri toplama ve analizi ile doğrulanmasına ihtiyaç vardır. Çalışmanın ikinci evresinde bir profesyonel öğretmen eğitimi programı uygulanmıştır. Bu program sırasında, öncesinde ve sonrasında veri toplanmıştır. Son olarak üçüncü evrede, ikinci evrede toplanan verinin analizi yapılmıştır. Bu analizler öğrenme ilerlemelerinde değişiklik ve iyileştirmeleri sağlamıştır.

Tablo 1 de yukarıda açıklanan evrelerin farklı detaylı gösterimi sunulmuştur. Bu gösterim ile iki farklı öğrenme ilerlemesinin geliştirilmesi için izlenen yollar ve veri toplama stratejileri, evreler kapsamında ele alınmıştır.

Veri Kaynakları

Çalışma kapsamında altı farklı veri kaynağı kullanılmıştır: a) yazılı değerlendirmeler, b) bilişsel görüşme formu, c) uzman paneli, d) öğretmen günlükleri, e) klinik görüşme formu, ve f) Fen Öğretmenlerinin Mühendislik Eğitimine Karşı Tutumları Ölçeği.

a. Yazılı değerlendirmeler

Hem öğretmen tutumları hem de öğretmenlerin mühendislik tasarım süreci kavrayışları konusunda öğrenme ilerlemesi geliştirmenin ilk basamaklarından birisi olarak ön ampirik veri toplanmıştır. Fen öğretmenlerine uygulanan veri toplama kaynağı internet üzerinden uygulanmıştır.

İki kısımdan oluşmakta ve toplam 11 adet açık uçlu soru içermektedir. İlk bölümde öğretmenlerin tutumlarına yönelik yedi soru bulunmaktadır. İkinci bölümde ise mühendislik tasarım sürecine yönelik dört soru bulunmaktadır. Uygulama öncesi sorulara iki uzmandan geri bildirim alınmıştır. Uzmanlardan biri ölçme alanından bir uzman diğeri ise eğitim programları alanında doktora öğrencisidir. Bunu takiben iki adet eğitim fakültesi lisans öğrencisi ile pilot uygulamalar yapılmıştır.

b. Bilişsel görüşmeler

Görüşmeler öncelikli olarak öğretmen tutumlarına yönelik geliştirilen ölçeğin iyileştirilmesi için yapılmıştır. Alan yazında ölçek maddelerinin niteliğinin artırılması ve iyileştirilmesi ile benzer bilişsel görüşmelerin uygulandığı görülmüştür (Sopromadze & Moorosi, 2016; Willis, 2015). Görüşme bulguları tutum üzerine geliştirilen öğrenme ilerlemesinin iyileştirilmesine de katkı sunmuştur.

Tablo 1. *Çalışmada İzlenen Yöntem Basamakları*

Adımlar	Eylemler
Alan yazın taraması	Varolan alan yazın taranır ve destek alınır
Yazılı değerlendirmeler	Açık uçlu sorular ile very toplanır
Her iki öğrenme ilerlemesinin ilk versiyonu geliştirilir	
Uzman paneli	Seviyeleri iyileştirmek için uzmanlardan görüş ve öneri alınır
Öğretmen kavrayışları öğrenme ilerlemesinin ikinci versiyonu geliştirilir	
Bilişsel görüşmeler	Özellikle öğretmen tutumları öğrenme ilerlemesi ve ölçeğe katkı sağlamak için fen öğretmenleri ile bilişsel görüşmeler gerçekleştirilir
Öğretmen tutumları öğrenme ilerlemesinin ikinci versiyonu geliştirilir	
Öğretmen eğitiminin uygulanması Tutum ölçeği, öğretmen günlükleri ve klinik görüşmeler	Öğretmen tutumları öğrenme ilerlemesini revize etmek için tutum ölçeği uygulanır Öğretmen kavrayışları öğrenme ilerlemesini revize etmek için öğretmen günlükleri ve klinik görüşmeler ile veri toplanır
Veri analizi	İkinci evrede toplanan veriler analiz edilir
Her iki öğrenme ilerlemesinin üçüncü versiyonu geliştirilir	

Görüşme sorularının hazırlanmasında üç kaynak özellikle ilham verici olmuştur; Shafer ve Lohse (2005), Sopromadze ve Moorosi (2016), ile Willis (2015). Görüşme formundaki tüm sorular her katılımcı için kullanılmamıştır. Görüşmenin doğasına uygun sorular görüşme formunda seçilerek, araştırmacıya yardımcı olacak ve önemli veriye ulaşacak şekilde kullanılmıştır.

c. Uzman paneli

Uzman paneli gerçekleştirmenin amacı alanında uzmanlardan öğrenme ilerlemelerine değerlendirme ve öneri almaktır. Çalışma kapsamında iki uzman paneli gerçekleştirilmiştir. İlki tutum üzerine geliştirilen öğrenme ilerlemesi hakkında yapılmıştır. Panele katılan uzmanların biri ölçme ve değerlendirme alanında çalışmalar yapmaktadır, diğer üç katılımcı ise rehberlik ve psikolojik danışmanlık alanında araştırma görevlisidir. İkinci uzman paneli mühendislik tasarım süreci üzerine geliştirilen öğrenme ilerlemesi hakkında yapılmıştır. Bu panele eğitim programları ve öğretimi alanında doktora yapan iki uzman ve FeTeMM alanında çalışmalar yapan bir uzman katılmıştır. Her iki panel sırasında notlar alınmış ve bu notlar daha sonra detaylı okunarak özetlenmiştir.

d. Öğretmen günlükleri

Öğretmenlerin mühendislik tasarım süreci kavrayışlarının detaylı olarak ortaya konması amacı ile veri toplanmıştır. Öğretmen eğitimine katılan 30 öğretmene uygulanmıştır. Toplam üç bölüm içermektedir. Bu bölümler ikinci evrede uygulanan öğretmen eğitimi içeriğine, mühendislik tasarım süreci öğrenme ilerlemesinin ikinci versiyonuna göre hazırlanmıştır. İki gün süren öğretmen eğitimi sırasında uygulanmıştır.

e. Klinik görüşmeler

Görüşmeler mühendislik tasarım süreci üzerine öğretmenlerin düşünme süreçlerini meydana çıkarmak ve öğrenme ilerlemesi seviyeleri oluşumu için daha detaylı veriye ulaşmaktır. Çalışma kapsamında uygulanan öğretmen eğitimine katılan 30 öğretmenden seçilen 10 öğretmen ile yapılmıştır. Görüşme formu öğretmen günlükleri ile uyumlu olan üç bölümden oluşmaktadır. Her bir bölümde mühendislik tasarım sürecinin farklı bir yönü vurgulanarak öğretmenlerin görüş ve değerlendirmelerine ulaşılmıştır.

f. Fen Öğretmenlerinin Mühendislik Eğitimine Karşı Tutumları Ölçeği

Ölçek geliştirilmesinin öncelikli amacı öğretmen tutumları öğrenme ilerlemesinin güvenirlik ve geçerliğine katkı sağlamaktır. Ölçek beşli Likert-tip olup, yanıt seçenekleri öğrenme ilerlemesinin seviyeleri ile paraleldir, olumsuz tutumdan olumlu tutuma doğru. Öğrenme ilerlemesi geliştirilirken onunla paralel bir ölçme aracı geliştirilmesine alan yazında rastlanmaktadır; Alonzo ve Steedle (2009), Nguyen ve Griffin (2012), ve Mahat (2008). Böylelikle öğrenme ilerlemesi seviyeleri ve geliştirilen ölçek arasında teorik ve ampirik bir eşleşme sağlanarak, daha güvenilir bir ölçme yöntemine ulaşılmaktadır.

Ölçek öğretmen eğitiminin hemen öncesine ve eğitimin son gününde olmak üzere iki kez uygulanmıştır. Çalışma kapsamında revize edilen ölçeğin öğretmen eğitiminde uygulanan versiyonu toplam 22 madde içermektedir. Her sorunun kesinlikle katılmıyorum ve kesinlikle katılıyorum arasında beş yanıt kategorisi vardır.

Örneklem

Tablo 2 çalışmanın katılımcılarını özetlemektedir. Tabloda sunulan katılımcı profiline ek olarak, çalışmanın ikinci evresinde uygulanan öğretmen eğitimine katılan 30 öğretmenin seçimi için çeşitli kriterler aranmıştır. Öncelikli olarak programın duyurulması için bir internet sitesi (https://tasarlayapogren.wordpress.com). tasarlanmıştır ve öğretmenler başvurularını bu internet sitesi aracılığı ile yapmışlardır.

Tablo 2. *Çalışmanın Katılımcıları*

	Katılımcılar	
	Tutum üzerine öğrenme ilerlemesi ve ölçek	Mühendislik tasarım üzerine öğrenme ilerlemesi
Yazılı değerlendirmeler	14 ortaokul fen öğretmeni	
Bilişsel görüşmeler	Bir FeTeMM seminerine katılan 10 fen öğretmeni	NA
Uzman paneli	Ölçme alanında uzman (n = 1), ve rehberlik ve psikolojik danışmanlık alanında uzman (n = 3)	Program geliştirme uzmanı (n = 2), FeTeMM eğitimi uzmanı (n = 1)
Öğretmen eğitimi	Türkiye nin farklı şehirlerinden katılım gösteren 30 fen öğretmeni	
Fen Öğretmenlerinin Mühendislik Eğitimine Karşı Tutumları Ölçeği	Öğretmen eğitimine katılan 30 fen öğretmen	NA
Öğretmen günlükleri	NA	Öğretmen eğitimine katılan 30 fen öğretmeni
Klinik görüşmeler	NA	Öğretmen eğitimi katılımcılarından seçilen 10 fen öğretmeni

Başvurular arasında seçim yapılırken izlenen kriterler şu şekildedir: a) FeTeMM eğitimi üzerine daha önce öğretmen eğitimine katılma durumu, b) mühendislik tasarım süreci ön bilgisi, c) cinsiyet, d) görev yapılan şehir, e) öğretmenlik deneyimi, ve f) devlet veya özel olarak okul türü. İlk iki kriterde bir dağılım yakalanması özellikle mühendislik tasarım süreci öğrenme ilerlemesi geliştirilmesi noktasında fayda sağlamıştır. Diğer dört kriter ise eğitim programının farklılık içererek daha nitelikli bir öğrenme ortamı sağlanmasını sağlamıştır. Öğretmen eğitimine toplam 300 ün üzerinde başvuru yapılmıştır.

Çalışmanın ikinci evresinde uygulanan öğretmen eğitimi

Hafta sonu iki gün süren bir eğitim verilmiştir. Eğitimin içeriği tasarlanırken üç perspektif etkili olmuştur: a) giriş kısmında sunulan ve alan yazın doğrultusunda belirlenen esas nitelikler b) alan yazından mühendislik tasarım süreci üzerine açıklamalar ve, c) mühendisliğin entegrasyonuna rehberlik eden bağlam entegrasyonu modeli (Moore vd., 2014a).

Eğitimin teması enerji, rüzgar enerjisi ve enerji dönüşümleri olarak belirlenmiştir. Eğiticileri mühendislik alanından ve eğitim alanından uzmanlar, alanda çalışan mühendisler ve rehberler olmak üzere toplam 15 kişi oluşturmuştur. Eğitimde iki gün boyunca yürütülen etkinliklerin öne çıkanları şu şekilde sıralanabilir mühendislerle panel, mühendisliğin doğasına giriş sunumu, FeTeMM eğitimi sunumu, mühendislik laboratuvarları gezisi, öğretmenlerin tasarım takımları olarak üzerinde çalıştıkları iki adet mühendislik tasarım görevi, farklı mühendislik tasarım etkinlikleri ve ürünlerinin sunulduğu sergi.

Veri analizi

Nitel veri analizi

Nitel verilerin analizi için toplanan veri kaynağına göre benzerlikleri olmakla birlikte farklı yöntemler izlenmiştir. Yazılı değerlendirme verisinin analizi için öncelikler tüm verileri pek çok kez dikkatlice okunmuştur. Bu okumalar ile taslak kodlar oluşturulmuştur. Ardından veriler tekrar okunarak, daha fazla ortaklık gösteren kodlar belirlenmiştir ve bazı kodlar elenmiştir. Sonrasında her kod için frekanslar hesaplanmıştır.

Bilişsel görüşme verilerinin analizi için öncelikler tüm veriler kayıt cihazından dinlenerek yazıya dökülmüştür. Daha sonra Ackerman ve Blair (2006) in kodlama taslağına göre iki ana tema belirlenmiştir. Veriler pek çok kez okunarak iki temanın altındaki kodlara ortaya konmuştur. Oluşturulan kod kitapçığı ışığında tüm kodların frekans hesabı yapılmıştır. Son olarak benzer frekans hesabı madde bazında tekrarlanmış ve revizeye neden olacak frekans değerleri hesaplanmıştır.

Öğretmen günlükleri ve klinik görüşme verilerinin analizi için, her iki veri toplama kaynağında paralel olan bölümlere göre bir kodlama rubriği oluşturulmuştur. Ardından veriler dikkatlice taranarak bazı değişiklikler yapılmış ve bu rubriklerin son hali verilmiştir. Ardından frekans hesapları ile bir ana rubrik hazırlanmıştır. Son olarak öğrenme ilerlemesinin ikinci versiyonu iler birlikte değerlendirilerek, üçüncü versiyon ortaya konmuştur.

Nicel veri analizi

Nicel veriyi uygulanan öğretmen eğitimine katılan öğretmenlerden Fen Öğretmenlerinin Mühendislik Eğitimine Karşı Tutumları Ölçeği ile toplanmıştır. Öğretmenler Likert-tipi ölçeği tamamlamışlardır. Verinin analizi R Studio istatistik analiz aracı ile yapılmıştır. Analiz sonuçları öğrenme ilerlemesi ve ölçeğin geçerlik ve güvenirliği ile ilgili bulguları sağlamıştır.

Analizin gerçekleşmesi için veriyi kullanarak Microsoft Excel formatında üç adet dosya oluşturulmuştur. Bu dosyalar daha sonra CSV formatında kaydedilmiştir. Bu üç dosya R Studio programının veriyi tanıyıp analiz edebilmesini sağlamıştır. Analiz gerçekleştirildikten sonra bulgular, üç dosyanın da bulunduğu büyük dosya içerisine R Studio programı tarafından otomatik olarak konmuştur. Tablo, figür gibi görsellerin yanında rakamsal sonuçlar da bulgular arasındadır.

Sınırlamalar

Öncelikli olarak çalışmanın başında toplanan yazılı değerlendirme verisinin online olarak toplanmış olması bazı kısıtlamaları getirmiştir. Diğer taraftan, bu veri toplama kaynağı için katılımcı seçimi yapılırken öğretmenlerin tutum ve mühendislik tasarım süreci kavrayışları anlamında farklılıklara yer verilmiş olsaydı daha zengin bir veri elde edilebilirdi.

Bir diğer nokta öğrenme ilerlemelerinin doğası ile ilgilidir. Bu süreç pek çok veri toplama ve analizi döngüsüne dayanmaktadır. Çalışma örnekleminin küçük olması ve çalışmanın üç evreden oluşan metot döngüsünü bir kez tamamlamış olması kısıtlamalar arasındadır. Ek olarak araştırmacının bilişsel görüşme ve klinik görüşme uygulanmasında yeni deneyim kazanıyor olması da bir kısıtlama olarak görülmektedir.
Tüm veri toplama araçları araştırmacı tarafından geliştirilmiştir. Bu süreçte hem uzman görüşleri alınmış hem de ufak pilot uygulamalar yapılmıştır. Ancak yine de hazır bir veri toplama kaynağı çalışmada bulunmamaktadır.

Geçerlik ve Güvenilirlik

İç geçerlik noktasında ve öğretmen uygulaması noktasında, uygulanan etkinliklerin yarısına yakını araştırmacı tarafından gerçekleşmiştir. Öğretmen eğitiminde veri toplayan ve etkinlikleri uygulayan kişinin aynı olması geçerliği tehdit etmiş olabilir. Bu durumun olabildiğince önlenmesi için eğitim ve mühendislik alanından farklı uzmanlar programda eğitim vermişlerdir. Toplanan nitel verinin fazla olması veri analizi noktasında güvenirliği etkileyebilmektedir. Bu anlamda iki farlı araştırmacıdan yardım istenmiş ve kodlama süreci birlikte de gerçekleştirilerek değer biçicilerarası güvenirlik hesaplanmıştır. Nicel veri analizi için de benzer bir süreç tekrarlanmıştır. İstatistik programı R Studio konusunda deneyimli bir başka araştırmacı aynı veriler üzerinden kendi bilgisayarında analiz gerçekleştirip benzer sonuçları almıştır.

Çalışmada pek çok farklı veri kaynağının kullanılması geçerlik ve güvenirliğe katkı sunmuştur. Veri kaynaklarının triangulasyon özellike tasarım temelli araştırma için de önem taşımaktadır.

Bulgular

Öncelikle çalışmanın birinci araştırma sorusu doğrultusunda bulgular paylaşılmıştır

1. Ortaokul fen öğretmenlerinin mühendisliğin fen eğitimine entegrasyonuna karşı tutumları bir öğrenme ilerlemesi ile nasıl ortaya konabilir?

1.a. Öğrenme ilerlemesinin ampirik doğrulamasının yapılması için öğretmenlerin tutumlarını ortaya koyacak bir ölçek nasıl ortaya konabilir?

Bu soruya çalışmanın verdiği yanıtlar Tablo 2 te verildiği üzere geliştirilen versiyonlar çerçevesinde ortaya konmuştur.

Birinci versiyonların geliştirilmesi

Bu versiyonun geliştirilmesi için iki yol izlenmiştir. Öncelikle ilgili alan yazından olumsuz tutumdan olumlu tutuma doğru seviyelerin oluşumuna katkı sağlayacak çalışmalar taranmış ve özetlenmiştir. Bu çalışmalardan çıkan özet çerçevesinde dört ana başlık öne çıkmıştır. Alan yazından öne çıkan 21 çalışma çalışmaya şu noktalarda katkı sağlamıştır öğretmen ve öğrencilerin FeTeMM ve mühendisliğe karşı tutumları, tutumla ilgili ölçme araçları ve madde hazırlanması, öğrenme ilerlemesindeki seviyelerin oluşturulması. Alan yazın taramasından sonra seviyelerle ilgili oluşan fikirlerin ardından fen öğretmenleri ile yazılı değerlendirmeler uygulanmıştır. Bu yazılı değerlendirme sonuçlarına göre toplam dört ana tema ve toplam 14 kod ortaya çıkmıştır. Temalar şu şekilde ortaya konmuştur: a) profesyonel gelişime ve mühendislik konusuyla ilgili öğrenmeye karşı olan ilgi, b) okul ortamının göz önüne alınması, c) öğrenci gelişimine değer verme, ve d) toplumun gelişimine değer verme. Dört tema altında oluşturulan kodlardan öne çıkanlara ise şu şekilde örnek verilebilir: profesyonel gelişim için fırsatlar, zaman, materyaller, FeTeMM alanlarına olan ilginin gelişimi, disiplinlerin entegrasyonunu anlama, bilginin uygulanması ve beceri gelişimi.

Birinci versiyonun geliştirilmesi için alan yazından ve yazılı değerlendirmelerden alınan sonuçlar birlikte detaylı olarak incelenmiştir. Bunun sonucu olarak öğrenme ilerlemesinin ve aynı doğrultuda geliştirilen ölçeğin tutumları ifade etme noktasında içereceği yönler şu şekilde belirlenmiştir: a) mühendislik entegrasyonu konusunda profesyonel gelişime ve öğrenmeye olan motivasyon (Lachapelle vd., 2014; Yasar vd., 2006), b) mühendislik eğitiminin öğrenci gelişimine olan katkısı (NGSS Lead States, 2013; NRC, 2012; Bybee, 2010), ve c) mühendislik eğitiminin toplum gelişimine olan katkısı (Lachapelle vd., 2014).

Öğrenme ilerlemesi seviyeleri ile paralel olacak şekilde "Fen Öğretmenlerinin Mühendislik Eğitimine Karşı Tutumları Ölçeği" de ilk versiyonu ile ortaya konmuştur. Bu ölçek Likert-tipi olup ilk versiyonu 25 maddeden oluşmuştur. Öncelikli olarak alan yazın ve yazılı değerlendirme sonuçlarına dayanarak, 56 maddelik bir madde havuzu geliştirilmiştir. Uzman görüşü neticesinde, çalışmasında problem olabilecek maddeler öğrenme ilerlemesi ile uyuşmayacak maddelerin elenmesi ile 25 maddelik ölçek elde edilmiştir. Ölçek maddelerinin her biri beş yanıt kategorisi içerip, her kategori öğrenme ilerlemesindeki bir seviyeye denk gelmektedir.

İkinci versiyonların geliştirilmesi

Öğrenme ilerlemesi ve ölçeğin ilk versiyonlarının iyileştirilmesi ve ikinci versiyonlarının geliştirilmesi için iki veri kaynağı sonuçları analiz edilmiştir. Bunlar uzman paneli ve bilişsel görüşmelerdir. Uzman paneli üç uzmanın katılımı ile gerçekleşmiştir. İlk versiyonları sunulmuş ve araştırmacı moderatörlüğünde bir tartışma yapılmıştır. Uzmanların ortak görüş ve değerlendirmeleri sonucu yapılacak iyileştirmeler şu şekilde ortaya konmuştur: a) ters madde yazmak, b) ölçeği hem öğretmen eğitimi öncesi hem de sonrasında uygulamak, c) seviye açıklamalarını daha anlaşılır hale getirmek, ve d) tüm maddelerin yazım ve kipini tutarlı bir hale getirmek. Bu adımın ardından bilişsel görüşme öncesi, ölçeğin geliştirilmesi adına ayrı bir uzman görüşü alınmıştır. İki farklı devlet üniversitesinde eğitim alanında çalışmalar yapan iki uzmanın görüşüne başvurulmuştur. Alınan geri bildirimler doğrultusunda öne çıkan değişiklikler iki başlık altında tamamlanmıştır: a) bazı ifadelerin değiştirilmesi, ve b) bazı ifade veya maddelerin ölçekten çıkarılması.

Bilişsel görüşmeler 10 ortaokul fen bilimleri öğretmeni ile gerçekleştirilmiştir. Uzman paneli ve uzman görüşü doğrultusunda revize edilmiş olan 23 maddelik ölçek bu görüşmelerde iyileştirilmek üzere kullanılmıştır. Analizler sonucu ortaya konan iki ana tema ve kodlar aşağıdaki tabloda verilmiştir. Ackermann ve Blair (2006)'ın kodlama taslağı kullanılmıştır.

Kodlara göre toplam frekans hesabının ardından, hangi madde ve ifadelerin nasıl değişmesi gerektiğinin daha açık ortaya konabilmesi için, madde bazında aynı kodlar için frekanslar hesaplanmıştır. Yüksek frekansa sahip olan maddelerde değişiklikler yapılmıştır. Her iki tema için kod frekans hesaplamaları ile yapılan değişiklikler ortaya konmuştur. Uzman görüşü ve klinik görüşmeler doğrultusunda öğrenme ilerlemesinin ve ölçeğin ikinci versiyonları oluşturulmuştur.

Üçüncü versiyonların geliştirilmesi

Üçüncü versiyonların geliştirilmesi için ölçeğin ikinci versiyonu uygulanan 30 öğretmen eğitimi katılımcısına hem eğitimden önce hem de eğitimden sonra uygulanmıştır. Elde edilen veriler R Studio istatistik programı ile analiz edilmiştir. Analiz sonuçları öğrenme ilerlemesi ve ölçeğin geçerlik ve güvenirlikleri ile ilgili önemli sonuçlar sağlamıştır.

Öncelikli olarak önemli sonuçlardan birisi ölçek maddelerinin öğretmenlerin tutum seviyelerini kapsamada yetersiz kalması olmuştur. Ölçek maddeleri çoğunlukla katılması öğretmenler açısından kolay olup, alınan yanıtlar çoğunlukla üst iki seviyede toplanmıştır. Ölçekteki maddelere katılımın katılımcı öğretmen profiline göre oldukça kolay olduğu gözlenmiştir.

Diğer bir sonuç olarak ölçek ile öğrenme ilerlemesinin koordinasyonun zayıf olduğu ortaya konmuştur. Bu durum öğrenme ilerlemesinin geçerliği açısında problemli bulunmuştur. Öğretmenlerin tutumlarında normal bir dağılımın sağlanamamış olması da bu bulguyu desteklemiştir. Özellikle öğrenme ilerlemesi seviye hizalanmasında problem yaratan maddeler tüm analiz sonuçlarını ortak değerlendirerek incelenmiştir. Ölçeğin güvenirlik sonuçları uygun bulunmuştur. Tüm sonuçlar ve analiz sonucunda elde edilen figürler ve değerler birlikte incelendiğinde, öğrenme ilerlemesinin üçüncü versiyonu için değişiklikler şu şekilde yapılmıştır: mühendisliğin öğrenci gelişimine ve toplum gelişimine olan katkısı noktasında öğretmenlerin tutumlarının pozitif olmasının daha kolay olması sonucu, bu noktalar üç seviye ile kısıtlanmıştır. Aynı durum öğretmenlerin mühendislik ve mühendislik entegrasyonu konusunu öğrenmeye olan motivasyonları için de geçerli olmuştur. Diğer taraftan, öğretmenlerin kendilerini profesyonel olarak geliştirmeye olan motivasyonları ile sınıfta mühendislik etkinlikleri uygulamaya olan tutumlarının daha iyi sonuçlar göstermesi nedeni ile yine beş seviyede kendini göstermiştir.

Öğretmen tutumları üzerine geliştirilen öğrenme ilerlemesi ve ölçek arasındaki ampirik bağlantının zayıf olduğu ortaya konmuştur. Bu nedenle yapılan değişikliklerden birisi ölçeğe, daha başarılı olan tutum ifadeleri noktasında daha fazla madde eklemesi yapılmıştır. Öğretmenlerin profesyönel gelişime karşı ve sınıfta mühendislik öğretme ve mühendislik tasarım etkinlikleri uygulama konularına ait maddelerin geçerlik ve güvenirlik bulguları kuvvetli olduğundan bu noktalarda literatürden örnek madde eklemesi yapılmıştır.

Bulguların ikinci kısmında, araştırmanın ikinci sorusuna yanıt aranmıştır:
Ortaokul fen öğretmenleri mühendislik tasarım sürecini kavrama noktasında daha düşük seviye bir kavrayıştan, yüksek bir kavrayışa doğru hangi seviyelerden geçerek ilerlerler?

Birinci versiyonun geliştirilmesi

Bu versiyonun geliştirilmesi için birinci araştırma sorusuna benzer şekilde iki yol izlenmiştir. Öncelikle ilgili alan yazından düşük kavrayış seviyesinden yüksek kavrayış seviyesine doğru seviyelerin oluşumuna katkı sağlayacak çalışmalar taranmış ve özetlenmiştir. Bu çalışmalardan çıkan özet çerçevesinde dört ana başlık öne çıkmıştır.

Alan yazından öne çıkan 21 çalışma çalışmaya şu noktalarda katkı sağlamıştır öğretmen ve öğrencilerin FeTeMM ve mühendisliğe karşı tutumları, tutumla ilgili ölçme araçları ve madde hazırlanması, öğrenme ilerlemesindeki seviyelerin oluşturulması. Alan yazın taramasından sonra seviyelerle ilgili oluşan fikirlerin ardından fen öğretmenleri ile yazılı değerlendirmeler uygulanmıştır. Bu yazılı değerlendirme sonuçlarına göre toplam dört ana tema ve toplam 14 kod ortaya çıkmıştır. Temalar şu şekilde ortaya konmuştur: a) mühendislik tasarım süreci kavramları ve b) mühendislik tasarım süreci. Bu iki temanın altında farklı kodlar üzerinden frekans hesapları yapılmıştır. İlgili alan yazın tarama ve derlemesi ve yazılı değerlendirme sonuçları ışığında öğrenme ilerlemesinin ilk versiyonu oluşturulmuştur.

İkinci versiyonun geliştirilmesi

Öğrenme ilerlemesinin ikinci versiyonunun geliştirilmesi uzman paneli sonucunda gerçekleşmiştir. Uzman paneli üç uzmanın katılımı ile gerçekleşmiştir. İlk versiyon sunulmuş ve araştırmacı moderatörlüğünde bir tartışma yapılmıştır. Bunun sonucunda öğrenme ilerlemesi seviyelerinde revizyonlara gidilmiştir.

Üçüncü versiyonun geliştirilmesi

Bu versiyonun geliştirilmesi için günlüklerden ve klinik görüşmelerden elde edilen veri analiz edilmiştir. Analiz sonuçları, öğrenme ilerlemesinin ikinci versiyonu ile birlikte değerlendirilerek üçüncü versiyona ulaşılmıştır.

Öğretmen günlükleri öğretmen eğitimine katılan 30 katılımcıya uygulanmıştır. Eğitimin her iki gününde öğretmenler günlüklerini doldurmuşlardır. Günlüklerde üç bölüm bulunmaktadır. Her bölüm için elde edilen verinin analizi için ayrı kodlama rubrikleri geliştirilmiştir. Bu kodlama rubriklerindeki ifadeler, ortak kod hesapları doğrultusunda oluşmuştur. Her üç bölüm için toplam üç rubrik oluşturulmuştur. Bunları her biri farklı öğretmen grubuna aittir. Bunlar öğretmen eğitimine katılan ve mühendislik tasarım sürecine göre gruplanan öğretmen gruplarıdır. Tüm kodlama rubrikleri tamamlandıktan sonra seviyelerdeki ortaklıklar dikkate alınarak kapsamlı bir kodlama rubriği ile bulgular bir araya getirilmiştir. Bu kapsamlı kodlama rubriği klinik görüşmelerin analizine ana taslak olmuştur ve bir nevi kod kitapçığı görevi görmüştür.

Klinik görüşmeler öğretmen eğitimi katılımcılarından seçilen 10 öğretmen ile, eğitimi takip eden iki hafta içerisinde gerçekleştirilmiştir. Yarıdan fazla öğretmen tarafından tekrarlanan kodlar, ifadeler kapsamlı kodlama rubriğinde korunmuştur. Daha sonra öğrenme ilerlemesinin ikinci versiyonu ile birlikte ele alınarak üçüncü versiyon ortaya konmuştur. Bu versiyon tabloda verilmiştir. İkinci versiyona göre öne çıkan önemli farklılıklar şu şekilde sıralanabilir, öğrenme ilerlemesinin üç bölümden oluşuyor olması, hangi mühendislik tasarım süreci adımlarının daha kolay ve zor kavrandığının ortaya konması, kriter ve kısıtlama gibi kavramlara kavrayış düzeyine göre nasıl yaklaşıldığının ortaya konması, tasarım süreci adımlarının sıralanırken nasıl hatalar yapıldığının ortaya konması.

Tartışma ve Öneriler

Tartışma ve sonuç bölümü, geliştirilen iki öğrenme ilerlemesinin son versiyonları, yapılan değişiklikler, değerlendirmeler ve öneriler çerçevesinde sunulmuştur.

Öğrenme ilerlemeleri halen yeni gelişmekte olan, hem öğrencilerin hem de öğretmenlerin gelişim düzeylerini sistematik ve veriye dayalı olarak ortaya koyabilecek bir yaklaşımdır (Furtak & Heredia, 2014). Özellikle Türkiye bağlamı için çalışma önder olması açısından önem taşımaktadır. Alan yazında öğretmenlerin mühendislik tasarım süreci kavrayış ve uygulama performanslarını ortaya koyan sistematik rubrikler olmakla beraber (Bailey & Szabo, 2007; Duncan, Diefex-Dux, & Gentry, 2011; Wendell, 2014) bir öğrenme ilerlemesi bulunmamaktadır. Öğretmenlerin gelişimlerinin sağlanması ve ölçülmesi, öğrenme ilerlemeleri geliştirmenin beş ana amacından birisidir (Kobrin vd., 2015). Çalışma ile öğrenme ilerlemelerinin önde gelen özelliklerinin tümü örneklendirilmiştir: (a) very toplama ve analiz döngüleri ile geliştirilme (Alonzo & Steedle, 2009; Shea & Duncan, 2013), (b) giderek ilerleyen seviyelerin gösterimi (Rivet & Kastens, 2012), (c) ölçme araçları ve öğretim programlarına taslak oluşturma, ve (d) ampirik veriye dayanma (Duncan vd., 2009).

Öğrencilerin toplum sorunlarına çözüm getirmeye katkı sağlayacak şekilde kendilerini geliştirmeleri noktasında fen eğitimin ve mühendislik arasında bir bağ bulunmaktadır (NRC, 2012). Öğretmenlerin kendilerini mühendislik etkinlikleri ve mühendislik entegrasyonu konularında geliştirmeleri (NRC, 2009; Yu et al., 2012) öğrencilerin gelişimini de etkileyecek bir durumdur (Li et al., 2016; Marra et al., 2000). Çalışmanın vurgu yaptığı, öğretmenlerin mühendislik kavram ve pratikleri alanında kavrayışlarının gelişmesi ve olumlu tutuma sahip olmaları kritik öneme sahiptir. Öğrencilerin fen ve mühendislik pratiklerine maruz kalmaları önemlidir (NRC, 2014). Günümüzde fen eğitiminde mühendislik kavram ve pratiklerinin yeri giderek artmaktadır (Akgündüz vd., 2015; MoNE, 2016; NGSS Lead States, 2013).

Çalışma ile daha önce verilmiş olan öğretmen eğitim programlarının geliştirilebilir yönlerine vurgu yapılmış ve örneklendirilmiştir. Bu yönlerden bazıları şu şekilde sıralanabilir programlarda yeterince nitelikli eğitmen olmaması, programların sistematik bir öğretim modeline dayanmaması, ve öğretmenlerin gelişimini ortaya koyacak yeterli sistematik araçların olmaması (Bayrakçı, 2009; Clarke & Hollingsworth, 2002; Guskey, 2002; Hynes & Santos, 2007; Kennedy, 2006).

Uygulanan öğretmen eğitimi programında bir sınıf içi uygulama kısmı bulunmamaktadır. Ancak bu tarz uygulamalar öğretmenlerin mühendisliği derslerine entegre etmelerinde etkilidir (Hynes & Santos, 2007). Öğretmenlerin sınıf içi davranışlarındaki değişiklikler onların tutumlarında da değişime yol açmaktadır (Hew & Cheung, 2014). Kelman (1958) ın tutum ile ilgili modelinde de değindiği gibi, tutumların değişme ve içselleştirilme noktalarında, sınıf içi deneyim ve gözlemlerin, gerçek okul ortamının rolü vardır. Öğretmenlerin henüz öğrendikleri üzerine yansıma ve değerlendirme yapacak zamanları olmamış olabileceği düşünülmektedir.

Tutum konusundaki öğrenme ilerlemesi ve ölçek arasındaki ampirik bağ, literatürdeki benzer çalışmalara göre zayıf bulunmuştur (Mahat, 2008; Nguyen & Griffin, 2012). Bu durumun nedenlerinden birisi katılımcı sayısının alan yazındaki öğrenme ilerlemesi geliştiren çalışmalara göre az olması olabilir (Duncan vd., 2016; Todd & Kenyon, 2015). Bir diğer nokta ise öğretmenlerin hem uluslararası hem de ulusal bağlamda henüz oldukça yeni ve ilgili çekici olan bir konuda eğitime katıldıktan sonra ölçekleri doldurmaları olabilir. Öğretmen eğitim programları öğretmenlerin yeni pedagojik yaklaşımlara karşı pozitif tutumlarını artırmada role sahiptir (Male, 2011; Kapanadze, Bolte, Schneider, & Slovinsky, 2015). Öğretmenlerin sınıfta mühendislik uygulamaları yapma ve öğrencilerine mühendislik tasarım sürecini öğretme konusunda öğrenme ilerlemesi ve ölçeğin daha başarılı olması üzerine düzenlemeler öğretmekten keyif alma (Lachapelle vd., 2014), öğretmeye karşı tutum (Van Aalderen-Smeets & Van Der Molen, 2013; Yu vd., 2012), ve sonuç-beklenti (Hart & Laher, 2015) noktalarında yapılmıştır. Öğretmenlerin mühendisliği öğretmen ile ilgili kendilerine güvenleri, ve rahat etmeleri de üzerinde çalışılabilecek yönlerdir (Cunningham vd., 2007; Hynes & Santos, 2007). Rick ve Stewart (2003) a göre bir konuyu öğretmede kendilerine güven duyan öğretmenler yeni yaklaşımları uygulamaya daha açık olmaktadır. Diğer taraftan mühendislerle etkileşim halinde olmak ve onların yaptıkları işin doğasını öğrenmek öğretmenlerin bakış açısı ve tutumlarını olumlu etkilemektedir (Nadelson vd., 2013). Öğretmen eğitiminde mühendislerle panel, sunum gibi çeşitli etkinliklerin yapılmış olması, öğretmenlerin tutumlarını program sonunda etkilemiş olabilir. Özellikle üst seviyelerde yanıtların toplanmış olması bir yönden bu şekilde açıklanabilir.

Öğretmenlerim mühendislik tasarım süreci kavrayışları üzerine geliştirilen öğrenme ilerlemelerinin bir ölçek gibi veri toplama aracı geliştirilmemiştir. Alan yazındaki daha açıklayıcı yaklaşan öğrenme ilerlemelerinde olduğu gibi for (Breslyn vd., 2016) açık uçlu sorularla seviyelerin detayı oluşturulmaya çalışılmıştır. Veri toplarken uygulanan ve öğretmenlerin düşünüşlerini ortaya koyan sorular ile kavrayışlarının olası seviyeleri ortaya konmuştur (Claesgens vd., 2008). Öğretmenlere ait ortaya konan seviyeler incelendiğinde alan yazınla birlikte çeşitli değerlendirmeler ortaya konmuştur. Öğretmenlerin düşük seviye bulundurdukları tasarım süreci adımları araştırma yapmak, ve problemin belirlenmesi olmuştur. Hsu vd. (2010) de benzer bir sonuca ulaşmıştır. Bu çalışma için bunun nedeni öğretmen eğitiminde ve dokümanlarda daha fazla vurgu yapılmış olan beş adımlı daha basit bir tasarım süreci modeli olabilir (Cunningham, 2008). Alan yazına göre beklenen üst seviyeye, süreç adımlarının tamamının açıklanması ve kısıtlama gibi tasarım süreci kavramlarının örneklendirilmesi (NRC, 2012; Moore vd., 2014b). üst seviyede de sunulamamıştır. Bunun nedeni öğretmen eğitimi etkinliklerinin tüm bu adım ve kavramları karşılamada yetersiz kalmış olması olabilir.

Mühendislik tasarım süreci öğrenme ilerlemesi Kobrin vd. (2015) tarafından geliştirilen, öğrenme ilerlemesi değerlendirme taslağı ile değerlendirilmiştir. Sonuçlara göre özellikle geliştirilmeye açık yönler biçim ve kullanışlılık olmuştur. İleride yapılacak yeni doğrulama çalışmaları ile bu yönlerin gelişimine katkı sağlanabilir. Bu çalışmada alan yazına örnek teşkil edilebilecek yönlerden birisi geliştirilen ve sonrasında uygulanan öğretmen eğitimine yönelik esas niteliklerdir. Mühendislik entegrasyonu konusunda öğretmenlere mesleki gelişim eğitimi vermek isteyen eğitimciler bu niteliklerin uygulanması noktasında çalışmadan yardım alabilirler. Fen öğretmenlerinin mühendislik entegrasyonu konusunda gelişmeleri için daha fazla benzer programa ihtiyaç duyulmaktadır (Dyehouse vd., 2014). Windschitl vd. (2012) tarafından geliştirilen öğretmenlere yönelik öğrenme ilerlemesinde olduğu gibi ilerideki çalışmalar, öğretmenlerin kavrayış ve tutumları dışında sınıf için performansları üzerine öğrenme ilerlemeleri geliştirebilirler. Çalışma fen alanına işaret etmekle birlikte, mühendislik tasarım süreci, matematik alanında da öğrencilere katkı sunmaktadır (Narode, 2011). Çalışmadan ilham alınarak, diğer FeTeMM alanlarında da tasarım sürecine yönelik eğitimler sağlanabilir ve çalışmalar yapılabilir.

APPENDIX N

TEZ FOTOKOPİSİ İZİN FORMU

ENSTİTÜ

Fen Bilimleri Enstitüsü [ ]

Sosyal Bilimler Enstitüsü [X]

Uygulamalı Matematik Enstitüsü [ ]

Enformatik Enstitüsü [ ]

Deniz Bilimleri Enstitüsü [ ]

YAZARIN

Soyadı : MESUTOĞLU
Adı : Canan
Bölümü : Eğitim Bilimleri Bölümü

TEZİN ADI (İngilizce) : Developing teacher learning progressions for K-12 engineering education: Teachers' attitudes and their understanding of the engineering design

TEZİN TÜRÜ : Yüksek Lisans [ ] Doktora [X]

1. Tezimin tamamından kaynak gösterilmek şartıyla fotokopi alınabilir. [ ]
2. Tezimin içindekiler sayfası, özet, indeks sayfalarından ve/veya bir bölümünden kaynak gösterilmek şartıyla fotokopi alınabilir. [ ]
3. Tezimden bir bir (1) yıl süreyle fotokopi alınamaz. [X]

TEZİN KÜTÜPHANEYE TESLİM TARİHİ: