THE ROLE OF ENGINEERING DESIGN-BASED INSTRUCTION ON PRE-SERVICE CHEMISTRY TEACHERS' STEM CONCEPTIONS AND SELF-REGULATION

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ABSTRACT

THE ROLE OF ENGINEERING DESIGN-BASED INSTRUCTION ON PRE-SERVICE CHEMISTRY TEACHERS' STEM CONCEPTIONS AND SELF-REGULATION

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The purpose of this study was to investigate the role of engineering design-based instruction on the pre-service chemistry teachers' STEM conceptions and adoption of self-regulation processes. During the instruction, the pre-service chemistry teachers engaged in a STEM activity based on the engineering design process (EDP) for four weeks for designing a drip irrigation system after they participated in theoretical STEM course.

The design of the study was basic qualitative research. Data were collected from the four pre-service chemistry teachers via semi-structured interviews and think-aloud protocol. Interview data were analyzed using inductive coding for STEM conceptions. Deductive coding was utilized to analyze data coming from think aloud protocol. Specifically, data were coded based on the five steps of the EDP (ask, imagine, plan, create, test, and improve). For self-regulation, data were examined under three main phases: forethought, performance, and self-reflection. Results indicated that implementation of the EDP through STEM activity enhanced pre-service chemistry teachers' conceptions of STEM in terms of underlining the importance of real-life problems. In addition, they expressed the nature of integration between STEM disciplines at the interdisciplinary and transdisciplinary levels. Furthermore, their self-regulation became diversified at the forethought phase and performance phase after practising the EDP. The study provides insight about the implication of the EDP to enhance the STEM conceptions and adoption of the self-regulation processes.

Keywords: STEM, Engineering Design Process, Self-regulation, Pre-service Teachers, Chemistry Education

ÖZ

MÜHENDİSLİK TEMELLİ EĞİTİMİN KİMYA ÖĞRETMEN ADAYLARININ STEM ANLAYIŞLARI VE ÖZDÜZENLEMELERİ ÜZERİNDEKİ ROLÜ

Yılmazoğlu, Elif
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Bu çalışmanın amacı mühendislik temelli eğitimin kimya öğretmen adaylarının STEM (fen, teknoloji, mühendislik, matematik) anlayışları ve özdüzenleme süreçlerini benimsemeleri üzerindeki rolünü araştırmaktır. Öğretmen adayları dört hafta boyunca mühendislik tasarım sürecini temel alan bir STEM eğitimine katılmıştır. Eğitim sürecinde teorik STEM eğitimi almalarının yansıra damla sulama sistemi tasarladıkları STEM etkinliğini gerçekleştirmişlerdir.

Araştırma deseni olarak temel nitel araştırma kullanılmıştır. Dört öğretmen adayından veriler yarı yapılandırılmış görüşmeler ve sesli düşünme protokolü aracılığıyla toplanmıştır. Görüşme verileri STEM anlayışları için tümevarımsal kodlama kullanılarak analiz edilmiştir. Sesli düşünme protokolünden gelen verileri analiz etmek için ise tümdengelimsel kodlama kullanılmıştır. Bu veriler mühendislik tasarım sürecinin beş adımına (sor, hayal et, planla, yarat, test et ve geliştir) ve özdüzenlemenin üç ana aşaması olan öngörü, performans ve özyansıtma aşamasına dayanılarak kodlanmıştır. Sonuçlar, STEM'in veriler mühendislik tasarım süreci yoluyla uygulanmasının, kimya öğretmen adaylarının STEM anlayışlarının gerçek hayat problemlerin öneminin vurgulanması bakımından geliştirdiğini göstermiştir. Katılımcılar STEM disiplinleri arasındaki bütünleşmenıin disiplinlerarası ve disiplinleri aşan boyutta olduğunu belirtmişlerdir. Ayrıca, veriler mühendislik tasarım sürecini uyguladıktan sonra katılımcıların öngörü ve performans aşamalarındaki özdüzenleme süreçlerinin çeşitlendiği görülmüştür. Çalışma, veriler mühendislik tasarım sürecinin STEM anlayışını geliştirme ve özdüzenleme süreçlerine etkileri bakımından çıkarımlarda bulunmaktadır.

Anahtar Kelimeler: STEM, Mühendislik Tasarım Süreci, Özdüzenleme, Öğretmen Adayı, Kimya Eğitimi

To my beloved family and Öykü

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LIST OF ABBREVIATIONS

EDP: Engineering Design Process

iSTEM: Integrated STEM

NGSS: Next Generation Science Standards

NSF: National Science Foundation

OECD: Organization for Economic Co-operation and Development

STEM: Science, Technology, Engineering, Mathematics

CHAPTER 1

INTRODUCTION

The overall structure of the study takes the form of five chapters, including this introductory chapter. The first chapter of this thesis presents brief overview of the background, significance, and purpose of the study, and definition of related terms.

1.1 Background of the Study

One of the most important events of the 21st century was assertion of approaching science, technology, engineering, and mathematics (STEM) from interdisciplinary perspective as educational initiative by National Science Foundation (NSF) of the USA in 1990s (Sandlers, 2009). The incentive for this approach aroused due to the inadequacy of US students' STEM skills which are essential for enhancing their competency in work lives and meeting technological demands of the society (Chiu & Duit, 2011; Martín-Páez, 2019; Siekmann & Korbel, 2016). Although “SMET” was used to describe the science, mathematics, engineering, and technology fields as an acronym at first, it has taken final form that is “STEM” by the NSF in 2001 (Marrero, 2014). Along with increasing attention in STEM education, however, there is a disagreement about how to define it. Debate continues about finding the best definition for STEM education at the paradigmatic axes of meaning of each discipline, number of emphasized disciplines, practices of disciplines, and context of the disciplines in which STEM is used (Bybee, 2013). Although practitioners personalize them in their definitions, prominent themes for STEM integration can be regarded as “centered on real-world problems or context,” “degree the disciplines were integrated,” and “roles of disciplines and pedagogies for conjunction with STEM integration" in the light of different definitions and frameworks (Moore et al., 2020).

Several attempts have been made to define STEM education conduced to appearance of the concept of "Integrative STEM Education." In 2006, Sanders and Wells published a paper in which they described integrative STEM education as an approach that poses teaching and learning between/among at least two STEM disciplines by emphasizing "purposeful design and inquiry" as a seminal component of integrative STEM education which based on the technology or engineering design with practices of science and mathematics. Engineering design is an important component of STEM and plays a key role in implementation in integrative STEM education. There exists a considerable amount of literature on engineering design in STEM education and these studies have suggested a variety of frameworks for process of engineering design depending on the number of steps and the emphasis of these steps for solving authentic problems systematically (Daugherty et al., 2018). English and King (2018) have showed the engineering design process (EDP) was mainly concerned with iterative process that consists of stages of description of problem, planning, designing, testing, redesigning, and communication of process. Another perspective has been adopted by Hynes et al. (2011) who argue the EDP as a stepwise approach that consists of clear identification of the need/problem, researching of the need/problem, brainstorming of possible solutions and determining the best solution, planning and constructing prototype, testing prototype, evaluation of solution, and communication about solution by contextualizing it as a way of organizing thoughts in these steps so that the best solution can be found for the need/problem. Lewis (2005) holds the view that even though there is more than one framework for the EDP, all these frameworks agreed on the presence of cognitive activity in the process. Systematic reviews about the EDP in STEM such as that conducted by Hafiz and Ayop (2019) showed that utilization of the EDP as a mean in STEM education resulted in positive effects on both cognitive and affective characteristics of students. Beside the cognitive activity, Estapa and Tank (2017) revealed that implementation of engineering design as a context for integration of STEM disciplines is beneficial to facilitating participation of real-world problems and to make content connections of STEM disciplines more explicit for practitioners of STEM.

As a practitioners of STEM education, roles of teachers in terms of organization of learning and teaching are incontrovertible. Koculu et al. (2022) indicated that readiness of teacher was determinant of educational quality of STEM education. This view is supported by Stohlmann et al. (2012) who stated that preparing and informing teachers for integrated STEM education is vital to achieve effective STEM education from the point of success of students in STEM disciplines. As aforementioned issues taken into the consideration, to meet the demands of changing world, raising citizens who are qualified in STEM disciplines has become a central issue for the countries that willing to get ahead in global economic competition (Akgündüz et al., 2015; Noonan, 2017). Despite research had been carried out on STEM education around the bullet points of K-12 teaching, teacher and teacher education; too little attention has been paid investigation of post-secondary teachers in STEM education (Li et al., 2020). Studies in the field of post-secondary STEM education have not treated the chemistry pre-service teachers in much detail and only few researchers have been able to draw on systematic research into knowledge of the pre-service chemistry teachers about STEM education. Studies of Trang et al. (2019) show the importance of training of the pre-service chemistry teachers so that they can design STEM integrated learning environments with the awareness of nature of STEM, implement integrative STEM teaching, and assess the process of STEM learning of students. In the same vein, Akaygun and Aslan-Tutak (2016) noted that education of the pre-service chemistry teachers about STEM improved their conceptions of STEM disciplines and perceptions about integration of these disciplines. Their work is complemented by Gunbatar-Aydin et al.'s (2018) study of application of the EDP in STEM by the pre-service chemistry teachers. This study revealed that the pre-service chemistry teachers' content knowledge in both chemistry and STEM has been developed by implementing the EDP throughout STEM course.

In view of all that has been mentioned so far has placed the EDP at the heart of our understanding of STEM implementation. Together, these studies outline that the pre-service chemistry teachers' STEM conceptions and cognitive activities might be enhanced when they have engineering design-based instruction since cognitive activity continues throughout the EDP in the form of organizing thoughts.

Ability to organize of thoughts toward specific goal such as finding the best solution to problem/need in the EDP point out self-regulation that is defined as "self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals" by Zimmerman (2000). Zimmerman's definition of self-regulation derived from the social cognitive theory of Bandura (1986). According to the social cognitive theory, triadic reciprocal causation between personal factors, environmental events and behavioral patterns interact with each other bidirectionally and agentic individuals are defined by considering relationship between these tenets. Although there is an obvious parallel between the social cognitive theory of Bandura (1986) and Zimmerman's (1989) initial approach of defining self-regulation in terms of triadic causation, Zimmerman's approach differs by emphasizing the effect of feedback on these three components in an individual's self-regulation (Zimmerman, 2013).

Zimmerman's attempts of explaining the factors that affect self-regulation processes and relationship between these processes resulted in evolving cyclical model of self-regulation (Zimmerman, 2000). Cyclical model of self-regulation based on the social cognitive theory examines the learning process and motivational beliefs of individuals in three phases that are named as forethought, performance, and self-reflection. These phases of cyclical model present the self-regulation processes before, during, and after learning. The forethought phase includes task analysis and self-motivation beliefs/values, the performance phase consists of self-control and self-observation, and the self-reflection phase involves self-judgement and self-reaction.

The phases of self-regulation model (Zimmerman, 2000) and processes of engineering design (English & King, 2015; Moore et al., 2014) might be consistent with each other. Task is examined to fulfill learning goal at the forethought phase of self-regulation model, and it might be supported with the step of the EDP that are ask and imagine in which description of problem is performed to meet the given criteria. Planning, designing, and testing steps might promote the application of the strategies used in the processes of performance phase. For example, self-monitoring process in the self-regulation model might be helpful for implementing testing in the EDP since it contains strategies to check whether the goal of the task attained or not like testing the model for meeting the criteria or not. The processes in the self-reflection phase in the self-regulation model might be related to redesigning in the EDP since redesigning has been performed to enhance the product based on the feedbacks and results. Similar to redesigning, self-reflection phase consists of the evaluation of judgements to decide to give up or continue to the given task.

To eliminate the uncertainty about the relationship between desired cognitive activity along the EDP and cyclical model of self-regulation (Zimmerman, 2000), Li et al. (2020) investigated the self-regulated learning behaviors. They have proposed a model in which cyclical model of self-regulation (Zimmerman, 2000) was amalgamated with observation, formulation, analysis, reformulation, and evaluation processes of engineering design. Likewise, in their study in which self-regulated learning of students was examined along the engineering design activity, Lawanto et al. (2013) pointed out that students who were successful in engineering design activity the ones who showed significant superiority forethought phase in terms of comprehending the requirements of the task in detail and developing strategies to meet them.

In conclusion, to be a powerful country in the international arena, a country must organize its educational goals in accordance with the requirements of the century. As previously noted, STEM provides a channel for reaching the educational goals for meeting these requirements (Martín-Páez et al., 2019) and when the EDP is perceived as the supplier of the context for STEM disciplines, boundaries between disciplines are faded away and 21st century skills are attained by future citizens in a holistic manner as it should be (English, 2016). The successful implementation of EDP requires adoption of self-regulation processes (Lawanto et al. , 2013; Li et al., 2020). However, learning experiences of teachers came to realize externally regulated or both externally and self-regulated manner mostly (Eekelen et al., 2005). Since embedding self-regulation in STEM education might break down the poor self-regulation cycle (Blackmore et al., 2021; Rutherford et al., 2018), development of self-regulation of pre-service teachers is important to become more successful in their science education (Arsal, 2009).

In this regard, an investigation to understand the EDP in STEM from cognitive level and how the practice of the EDP by the pre-service chemistry teachers can contribute to their conceptions of STEM is important. Therefore, by taking the aforementioned issues into consideration, the aim of the present study is to understand the role of engineering design-based instruction on the pre-service chemistry teachers' STEM conceptions and adoption of self-regulation processes.

1.2 Significance of the Study

This study offers an exciting opportunity to provide an insight of how application of the EDP in the context of environmental chemistry as a part of engineering design-based instruction plays a role on STEM conceptions and adoption of self-regulation processes of the pre-service chemistry teachers. While some research was carried out to show how pre-service teachers' STEM conceptions change after implementing STEM activities, most of these studies were conducted with science teachers (e.g., Alan et al., 2019; Kececi, 2023; Ryu et al., 2019) and limited number of studies exists which investigates STEM conceptions of the pre-service chemistry teachers (Berisha & Vula, 2021; Isnaini et al., 2023). Therefore, this study is beneficial to make specific contribution to the studies about the state of art for STEM conceptions of the pre-service chemistry teachers.

Among the STEM disciplines, acquiring the engineering knowledge by the pre-service teachers is considerably challenging with respect to the others since being competent in STEM disciplines requires pedagogical practices with domain-specific content knowledge (Schulman, 1986) and teachers who have opportunities to become experienced in engineering teaching practice can be found merely (McDonald, 2016). Pave the way for increasing the number of qualified teachers who are knowledgeable to implement engineering practices, the Next Generation Science Standards (NGSS) (2013) established a framework that was based on “A Science Framework for K-12 Science Education” and set context of science and engineering practices together as condition to fulfill students’ learning of core ideas and/or crosscutting concepts of these disciplines. The subject of the STEM activity of the present study was chosen as an environmental chemistry problem that was solved by implementing the EDP is parallel to the framework of the NGSS in terms of choosing context of science and engineering practices. Therefore, the present study contributes to the literature by providing an example of implementation of science and engineering practices together and the role of this implementation on enhancing STEM conceptions of the pre-service chemistry teachers.

Engineering in STEM has grown in importance thanks to the studies exploring the conceptions of the pre-service teachers about the EDP. For instance, research about conceptions of the pre-service teachers for integrated STEM based on engineering design conducted by Widiastuti et al. (2020) revealed that deficiency of exposing engineering design-based activities during pedagogical coursework causes problems of integration of STEM disciplines and brought the need for emphasizing the EDP in STEM education into focus. Moreover, in their study Mangiante and Moore (2019) attempted to explain importance of preparation of the elementary pre-service teachers for engineering-based design process with science context to be able to scaffold students by analyzing and responding their ideas during the EDP. In the similar vein, the study of Sahiner and Ünlü (2022) with the elementary school teachers revealed the EDP activities play a role to increase teachers' STEM awareness, affecting their engineering perceptions positively. Additionally, Kuvac and Koc (2023) conducted a study with middle school teachers to explain how stereotypical perceptions of the science teachers about engineering discipline changes with STEM education. Since related literature is likely to explain the importance of the well executed EDP in STEM education by the pre-service teachers at elementary and middle school levels, the present study makes a contribution to engineering design-based instruction literature by broadening the scope of the EDP in STEM education working with the pre-service teachers at secondary level and investigating the role of the EDP in their STEM conceptions. Although, there are studies that discuss the EDP in STEM education from miscellaneous perspectives as mentioned above to provide deeper knowledge about it, apart from Gunbatar et al. (2022), there is a general lack of research in how the pre-service chemistry teachers' knowledge of STEM has changed with practicing the EDP. The present study helps to fill a gap in understanding the role of engineering design-based instruction on the STEM conceptions of the pre-service chemistry teachers by emphasizing the importance of preparing these teachers to integrate engineering design into chemistry topics at secondary level.

Practicing engineering design-based instruction is more than the application of domain-specific knowledge. To deepen the understanding of the EDP in STEM education requires investigating the individuals' cognitive activities during the EDP. The investigation of the self-regulation processes during the EDP can be one of the best ways for obtaining deeper understanding about what happens during these processes (Grinsven & Tilleman, 2006; Shin,1998; Souvignier & Mokhlesgerami, 2006; Weinstein et al., 2000). To illustrate, Fang and his friends (2023) investigated the effect of self-regulation approach on students' STEM skills and self-regulation by using a concept map as an organizing tool for learning STEM found that concept mapping-based self-regulated learning approach is beneficial for developing STEM skills and self-regulation of students. Additionally, Meral and Yalçın (2022) revealed the effect of entrepreneurship-based STEM instruction on self-regulation skills of students. Similarly, there are studies that state the lack of STEM conceptions of pre-service teachers were diminished with the implementation of the EDP (Aydin-Gunbatar et al., 2018; Radloff & Guzey, 2016). There are also studies which shows the importance of adoption of self-regulation processes by the pre-service teachers. For example, in their study Lee and Turner (2016) indicated the importance of institution the planning and self-monitoring for learning course content for the pre-service teachers. Another study that was conducted by Yoon et al.(2014) has revelaed that the pre-service chemistry teachers' self-regulated learning skills and self-evaluation have developed when they dealing with the problems whose solutions require the steps similar to the EDP such as understanding the problem, generating the possible solutions, determining the best solution, solving problem by experiments and evaluation.

Accordingly, the findings of the present study are useful to expand our understanding about engineering design-based instruction by investigating it with the lens of self-regulation. Because the present study proposes the overlapping between the processes of engineering design and self-regulation, it investigates how the EDP might enhance self-regulation and which specific self-regulation processes are adopted during the steps of the EDP, it contributes to the literature about both self-regulation and STEM education.

To sum up, the present study makes a contribution to the STEM education research by taking the EDP activity as the objective of STEM education in environmental chemistry content, investigating the conceptions of the pre-service chemistry teachers about STEM and EDP, scrutinizing the self-regulation in the EDP of STEM and adopting qualitative approach to gain deeper understanding of STEM conceptions and adoption of self-regulation processes.

1.3 Purpose of the Study

This study seeks to understand the role of engineering design-based instruction on STEM conceptions and adoption of self-regulation processes of the pre-service chemistry teachers in the context of environmental chemistry. The following research questions guides the study:

What is the role of engineering design-based instruction on the pre-service chemistry teachers' STEM conceptions and adoption of self-regulation processes in the context of environmental chemistry?

1.4 Definition of Related Terms

1.4.1 STEM

Even there is a consensus about what acronym of STEM (science, technology, engineering, and mathematics) indicates, meaning of STEM is discussed from different perspectives. Hasanah (2020) labelled STEM in the subsets that were discipline as practicing of at least two STEM subjects, instruction as a natural linkage between disciplines, field for continuing STEM pipeline, and career related with STEM fields.

With this in mind, throughout this study, the term STEM is used to refer to as a discipline and instructional approach.

1.4.2 STEM Education

Various approaches to defining STEM led to the different definitions of STEM education. These definitions can be classified under the categories of referencing four disciplines while emphasizing the meaning of only one discipline, considering STEM disciplines as four distinct disciplines with same importance, and regarding four disciplines are integrated within STEM education (Bybee, 2013; Marrero et al., 2014).

Throughout this study, the term STEM education refers to the integration of four disciplines within STEM education (Bybee, 2013; Marrero et al., 2014) which can be operated in all educational levels by all teachers (Brown et al., 2011; Kennedy & Odell, 2023).

1.4.3 Integrated STEM Education

Although a variety of definitions of the term integrated STEM education have been suggested, this study utilizes the definition suggested by Bryan et al. (2015) who define it as "teaching and the learning of the content and practices of disciplinary knowledge which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies." (p. 23)

1.4.4 Engineering Design Process (EDP)

While a variety of definitions of the term EDP have been suggested, this thesis employs the definition suggested by English and King (2015) which thematized the constituents of the EDP in five major steps: problem scoping, idea generation, design and construct, design evaluation, and redesign. This definition simplifies the nomenclature of ask, imagine, plan, create, test, and improve, developed by Moore et al. (2014).

1.4.5 Self-regulation

Throughout this study, the term self-regulation refers to "the self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals." (Zimmerman, 2000, p.14)

1.4.6 Self-regulated Learner

Zimmerman and Pons (1986) defined self-regulated learner as an active participant of his/her own learning metacognitively by planning, setting goals, self-monitoring, and self-evaluating during learning process, motivationally in terms of the self-attribution, self-efficacy, and intrinsic task interest and behaviorally by structuring and selecting learning environments for acquisition of knowledge

CHAPTER 2

LITERATURE REVIEW

This thesis seeks to understand the role of engineering design-based instruction on STEM conceptions and adoption of self-regulation processes by the pre-service chemistry teachers in the context of environmental chemistry. In line with this purpose, literature about emergence of STEM, STEM education, integrated STEM education, engineering design-based instruction, the social cognitive theory, and self-regulation framework of Zimmerman are explained in this chapter.

2.1 Conceptualization of STEM

STEM has aroused in U.S. as a result of two important historical events that ignited the scientific and technological developments: World War II and the launch of Sputnik by Soviet Union (White, 2014). During World War II, studies of scientists, engineers, and mathematicians has gained momentum to set on world domination by inventing technologies like atomic bomb. Information and experiences obtained from these studies carried STEM knowledge one step further. Theoretical and practical inventions made huge contribution to STEM during World War II whereas launching of Sputnik was cornerstone of progression of STEM. Successful launching of satellite “Sputnik” has provided a fillip for technological investment for space duties in U.S. and blazed a trail in establishment of National Aeronautics and Space Administration (NASA). NASA serves as a driving force for funding STEM initiatives since successful space missions require the usage of science, engineering, mathematics, and technology together (Dick, 2008). As a result of this, STEM was promoted due to the need of scientific knowledge and engineering to develop space technologies (Bybee, 2010).

For the first time, to represent science, technology, mathematics, and engineering “SMET” was coined as an educational term by U.S. National Science Foundation (NSF), afterwards abbreviation “STEM” was exerted to prevent phonetic problems of SMET (Dugger, 2010; Sanders, 2009). Despite of bringing the solution for the phonetic problem, acronym STEM embodied another problem which was remanding of a biological term “cell” (Keefe, 2010, as cited in Bybee, 2010). Although, actions were taken familiarize to what STEM stands for to overcome this problem, the book “The World Is Flat” written by Freidman (2005) has led to resurgence of U.S. citizens about STEM by underlining threat of China and India on the economy of U.S. thanks to their advancements in STEM (Sanders, 2009). Therefore, economic turmoil of country was correlated with STEM shortages in terms of workforce who skilled in science, mathematics, and engineering (Salzman & Douglas, 2023). Emergence of the relationship between STEM and global economy has been precursor to breakthrough in importance of understanding STEM for the future of countries (Marginson et al., 2013). To broaden the scope of STEM education for all levels of national education, National Science Committee published “A National Action Plan for Addressing the Critical Needs of the US Science, Technology, Engineering and Mathematics Education System.” in 2007. After that, US President Barack Obama publicized the federal government’s “Federal Science, Technology, Engineering and Mathematics (STEM education 5-Year Strategic Plan)” in 2013. All together these attempts contributed to dawn of blueprint for more systematic implementation of STEM (Zhan et al., 2022).

In the light of these developments, analyzing the meaning of STEM was asserted by scholars and politicians (Douglas & Strobel, 2014; Gao et al., 2020). In an investigation into meaning of STEM, Breiner et al. (2012) found that there is not common operational definition for STEM. In their study, they have worked with faculty members of university from STEM and non-STEM disciplines. Their study revealed that the faculty members were knowledgeable about STEM conceptions and comprehend STEM as separate disciplines of science, technology, engineering, and mathematics while only some of them mention about merging disciplines in STEM. Likewise, study conducted by Sanders (2009) argued that meaning of STEM and STEM education should be different. Theoretically, STEM education differs from STEM with the interaction of the science, technology, engineering, and mathematics. However, he claimed that there is not a difference between STEM and STEM education in practice since science, technology, engineering, and mathematics are disciplines whose rules, practices, philosophies, and approaches are distinctive. Therefore, it is not easy to bring them together like as in its acronym. A broader perspective has been adopted by Gonzalez and Kuenzi (2012) who proposed that definition of STEM pointed out science, technology, engineering, and mathematics separately. They noted that STEM has occupational nexus as well as educational goals and it comprehends formal and informal environments. They also reported the topics such as national security, education, federal science, and workforce to maintain their place STEM Federal policymakers' agenda. Overall, there seems to be some evidence to indicate that knowledge and practices of science, technology, engineering, and mathematics amassed separately in definition of STEM and defining STEM as an educational term requires special attention was discussed by scholars and politicians.

In view of all that has been mentioned so far, one may suppose that utilization of STEM as an educational term is analogous with structure of scientific revolutions that suggested by Kuhn (1962). In his book; "The Structure of Scientific Revolutions"; Kuhn proposed that science progresses with revolutions and these revolutions are non-cumulative (1962). According to him, the structure of scientific revolutions starts with "pre-paradigm" and continue with "normal science", "anomaly", "crises and emergence of scientific theory", and "scientific revolution". His model for the structure of scientific revolutions is cyclical that means after scientific revolution, it might start again if the need of more premising paradigm evolves. Similarly, traditional education system could not catch the notions of global industry and anomalies like economic depression came to raise. Then anomalies turn to educational crises because of absence of skilled individuals in the science, engineering, and mathematics to develop technologies. Crises came to the conclusion with introduction of STEM is a new educational paradigm. However, because obtaining the results of the new strategy or method on student's learning and educational practices takes long time, defining STEM as scientific revolution is assertive for now (McComas & Burgin, 2020).

2.2 STEM Education

The NSF has promoted an incentive to make research about learning science, technology, engineering, and mathematics and reaped the benefit at formation of STEM education (Bullock, 2017; Hoeg & Benzce, 2017; Yager, 2015). On the one hand, plenty amount of research about STEM education were conducted and there are ongoing studies about it, on the other hand efforts to conceptualize definition of STEM education has not come to fruition still (Aguilera & Ortiz-Revilla, 2021; Brown et al., 2011; Holmlund et al., 2018). Therefore, generalizability of much published research on definition of STEM is problematic and needs to be explained in detail based on the focuses of different definitions.

A recent study by Hasanah (2020) involved literature review of STEM education to understand the prominent definitions. He proposed that the most prevalent ideas about STEM education have circled around the four categories which were STEM as discipline, instruction, field, and career. Defining STEM as a discipline is related with practicing of at least two STEM subjects while defining as an instruction considering STEM education as a natural linkage between STEM disciplines. Based on the results of reviewed literature, defining STEM as field and career were more focused on STEM pipeline than discipline and instruction. The studies defining STEM education from the idea of field showed that besides the norms and practices of science, technology, engineering and mathematics, norms and practices of social and political sciences were included. In addition to that, definition of STEM education as field recognized as catalyst for graduating students from STEM fields. STEM as career, it can be thought as extension of graduating students from STEM fields, concentrated on STEM field related careers of students.

A different perspective has been adopted by Jurdak (2016) to present the different definitions of STEM education. In his book "Learning and Teaching Real World Problem Solving in School Mathematics" provided literature review about STEM education that has uncovered notions of it and showed three distinctive categories. First, STEM education as a literacy, it means lifelong process of practicing the knowledge of science, technology, engineering, and mathematics from school settings to social/cultural settings. Second, STEM education as pedagogy that is different pedagogies arouse different approaches to implementation of educational goals thus instructional design and building prototype are the pivots of different pedagogies. Third, STEM education as curriculum in which four disciplines of STEM either hold their characteristics or not and both of these structures need STEM specific goals, practices and outcomes.

Other researchers have focused on students for defining STEM education in terms of their problem-solving ability in authentic learning activities (Breiner et al., 2012; Burrows & Slater, 2015; Jurdak, 2016; Morrison, 2006). For example, Merrill (2009) has defined STEM education "STEM teaching and learning focuses on authentic content and problems, using hands-on, technological tools, equipment, and procedures in innovative ways to help solve human wants and needs." (as cited in Barakos et al., 2012, p. 4). Definitions that centered on students' skills and practices have caused to arise of questions related with scope of authentic content, problems, and followed procedures. Casting around the new terms for defining STEM education has resulted in introduction of "integrated" STEM education.

STEM integration, integrative STEM and interdisciplinary STEM are other terms that were used by scholars (Moore et al., 2020). Although there are contradictions about the usage of "Integrative STEM" (Sanders, 2009) and "STEM Integration" (Wells, 2013) because "Integrative STEM" was denoted to dynamic process which focuses on students while "STEM Integration" static process which focuses on teachers (Martín-Páez et al., 2019), throughout this chapter way of integration of disciplines will be the concern regardless which one is correct denomination of it.

Preliminary work on integrated STEM education was undertaken by Sanders (2009). He demonstrated the integrated STEM education as learning and teaching along at least two subjects from STEM disciplines or at least one subject from STEM disciplines and other school subjects with specific pedagogy of "purposeful design and inquiry." Sanders (2009) put this pedagogy in the center of integrated STEM education because in the context of technological designing and problem-solving with the application of mathematics and scientific inquiry, engineering solutions of real-world problems enables to merge scientific inquiry with design challenge intentionally. Similarly, Bryan et al. (2015) defined integrated STEM education as learning and teaching knowledge and practices of science and mathematics with the integration of engineering practices and its related technologies. They also emphasized the attainment of learning goals of science, technology and engineering was primary concern, but the goals of any other school subjects were also welcomed. In another study, Moore et al. (2014) indicated that blending of some or all of STEM disciplines by giving the value of linking up STEM subjects from these disciplines with real-world problems is a way of defining integrated STEM education. Different than Sanders (2009) and Bryan et al. (2015), Moore et al. (2014) claimed that STEM integration can be practiced without time restriction such as one class hour or throughout the time of unit (Moore et al., 2014, as cited in Kelley & Knowless, 2016). Unlike the other studies, Wells (2013) analyzed the implementation technological and/or engineering design was not only the providing a way of teaching and learning knowledge and practices science and mathematics but also the purposeful way of teaching and learning knowledge and practices of engineering by assenting to active role of students in their learning. He also asserted that there is a natural overlapping between STEM disciplines that provides continuity in education both formal and informal educational environments. Together, these studies outline that there are different hallmarks of integrated STEM education. These hallmarks can be united under the headlines of providing real-world problems, the way of connection of disciplines, and degree of integration of disciplines.

The definition of integrated STEM education includes real-world problems that were similar to authentic problems that scientists, mathematicians and engineers were deal with in reality (Hsu & Yeh, 2019; Juškevičienė et al., 2020). The reason of why scholars have mentioned the real-world problems in the definition of integrated STEM education is related with the aim of raising citizens who possess the 21st century skills and so keeping up with the necessities of current global economy (Barcelona, 2014; Khalil & Osman, 2017; Lafifa et al., 2023). Greater part of background information about the place of real-world problems in the definition of integrated STEM education is related to the aims of STEM education. However, to be able to gain insight about the way of connection of disciplines and degree of integration of disciplines in integrated STEM education demand broad range of information about the nature of STEM.

In the definitions of integrated STEM education, requirement of at least two STEM disciplines was indicated for integration (Sanders, 2009; Moore et al., 2014). Way of connection of disciplines in integrated STEM education does not mean teaching or/and learning two disciplines together (Bryan et al., 2015). Integration of STEM disciplines is more than aggregate of science, technology, engineering, and mathematics. There is a "seamless web" between STEM disciplines (Ortiz-Revilla et al., 2020, p. 864). Since the problems encountered in the real-world is multifaceted, they cannot be solved isolation of STEM disciplines from each other (Li, 2014; Roehrig et al., 2021; Son et al., 2017). Furthermore, STEM disciplines have some common grounds of practices and big ideas which bring homogeneity of distribution of knowledge and experiences along these disciplines (Nadelson & Seifert, 2017; Nathan et al., 2013). Harlen (2010) explained big idea about that is related with the "habits of mind," thinking habits toward seeing and solving problems of STEM practitioners, and big idea of that is related with the specific notions of STEM disciplines like iterative process of engineering design. This view supported by Chalmers et al. (2016) who proposed the role of big ideas on transfer of knowledge and experiences along STEM disciplines in a way of within discipline big ideas (implementation of one discipline into other), cross-discipline big ideas (common features of disciplines) and encompassing big ideas (conceptual and content encompassing) representations. Overall, these studies resolve the intricate pattern of integration of STEM disciplines.

Another important hallmark to gain better insight about the integrated STEM education understanding the degree of integration of STEM disciplines beside the way of connection of them. There are three forms of integration that are content, supported content, and context integration. Content integration is actualized when units or practices that have various learning goals from different disciplines exist whereas in supported content integration one subject of discipline is covered with the help of learning goals of other subject of discipline. Different from the content and supported content integration, context integration is useful when situated learning is possible with the context of one discipline to attain the goal of other discipline (Bryan et al., 2015). All of these forms of integrations contain four levels from lower to higher that are disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary. Disciplinary form of integration occurs when each STEM discipline learned based on silo approach. In the same manner with disciplinary approach, learning of STEM disciplines happens separately in multidisciplinary form of integration but there is a common theme while learning of disciplines. Interdisciplinary approach, however, similar concepts and skills from two or more STEM disciplines to go beyond the comprehension of these disciplines. As the most advanced form of integration, transdisciplinary integration demands the application of knowledge of STEM disciplines to real-world scenarios (Vasquez et al., 2013, as cited in English, 2016).

Together, these studies outline that the definition of integrated STEM education has been the subject of a significant amount of literature. There is a parallel between the disparities in defining STEM education and integrated STEM education. In other words, many researchers have argued that how operational definition of integrated STEM education should be identified so that measurable criteria for degree of integration of STEM disciplines can be determined.

In view of all that has been mentioned so far, one may suppose that multiple definitions of STEM education pave the way of gaining insight about the dynamics of it and understand the rationality behind the terms used in these definitions. As a result of this, well-suited STEM definition might be borrowed for making meaningful studies about it. In the light of this information, position of the present study to define the integrated STEM (iSTEM) is the one that Bryan et al. (2015) was proposed because their definition has features common to the present study like the emphasize on the learning of content and practices of science with the integration of engineering design practices.

2.2.1 Studies on STEM Education

There is a large volume of studies investigating the understanding of pre-service teachers about STEM education. For example, in her study, Kececi (2023) has investigated the change in STEM understanding of pre-service teachers throughout STEM education process. Participants of the study were informed about STEM with the lectures about its definitions, history, learning and teaching models as well as the examples of STEM applications. After that, STEM project was performed by the participants. Data were collected with semi-structured interviews. Analysis of data revealed that after theoretical and practical application of STEM, participants' STEM definitions became more comprehensive. Yet, there was plethora of STEM definitions based on the combination or integration of disciplines and solving daily life problems. Additionally, gaining theoretical and practical experiences have increased pre-service teachers' STEM competency and beliefs about the importance of STEM education. One of the interesting results of the study was that only one group chose the engineering-based STEM approach for STEM project. In addition to the having a difficulty in integration of STEM disciplines, together this result underlines the need of further studies about the integrated STEM education in engineering-based STEM approach.

Lawson et al. (2021) also found that being part in STEM activity can enhance the understanding of science and mathematics pre-service teachers about STEM education. Data were collected with open-ended survey and lesson sketches to understand STEM knowledge and challenges that participants experienced during STEM activity respectively. Results of their study showed that pre-service teachers possessed better insight about STEM after taking part STEM unit in terms of recognizing the attainment of the subjects of STEM disciplines explicitly in STEM activity and get into the perspective of identifying data as seed for connecting of STEM disciplines and real-world.

This view is supported by Berisha and Vula (2023) who identified the improvements in the pre-service teachers' integrated STEM education knowledge and their points of view about implementation of integrated STEM education as teaching approach. After taking the lesson about STEM and its teaching practices, participants have prepared lesson plans in the form of integrated science and mathematics by working as a group and then presented it. Data were collected by using surveys, lesson plans, and presentations. Results of data indicated that being informed about iSTEM and practicing it with preparing lesson plan made difference on pre-service teachers' understanding and about STEM positively as well as increasing their desire of designing STEM integrated lesson plans.

Several studies have linked practices of integrated STEM education with science education (Çinar et al.,2016; Fırat, 2020; Khureerung, 2022; Siew et al., 2015; Yip, 2020). To determine the parameters that influence the conceptualization of STEM education, Putra et al. (2021) have conducted quantitative study with 604 pre-service science teachers to investigate the relationship between the science content knowledge, STEM self-efficacy, and STEM anxiety. Result of correlational analysis showed that science content knowledge is a prominent factor and prior condition of conceptualizing STEM education and being capable of integrating subjects of STEM disciplines by pre-service science teachers.

Similarly, in a study which set out to determine the effect of STEM practices on pre-service science teachers, Alan et al. (2019) found that knowledge and awareness of iSTEM and problem-solving skills of pre-service science teachers have developed after theoretical and practical period of STEM training. Researchers examined the data that were collected with both quantitative (problem solving inventory test) and qualitative (diaries) methods. Both for promoting the integrated teaching knowledge of STEM and investigating its effect on problem solving skills of them, pre-service science teachers designed simulation by choosing a subject from national middle school science curriculum. Results of this study indicate that problem-solving skills of pre-service science teachers has improved after iSTEM practice. In addition to this, pre-service science teachers consider integration of STEM disciplines as condition for obtaining better learning outputs, so they stated its importance and necessity for their professional area.

Furthermore, practicing STEM education through the chemistry subject by the pre-service chemistry teachers formed the central focus of a study by Ahmad et al. (2018). In their study, participants designed and implemented lesson plan in which 5E instructional model was developed for the content of energy change in chemical reactions. In their lesson plan, they stated how integrated STEM education was performed through the application of the knowledge and procedures of STEM disciplines in the stages of 5E model. Results of the study showed that utilization of 5E model for practicing integrated STEM education provided an opportunity for the pre-service chemistry teachers to develop chemistry contents that promote active learning of students.

The studies presented thus far provide evidence that theoretical and practical applications about STEM education enhance STEM conceptions of pre-service science teachers. However, there is a need for more investigation about STEM conceptions and integrated STEM education implementations of the pre-service chemistry teachers. Launching of “Systems Thinking in Chemistry for Sustainability: Toward 2030 and Beyond” project by International Union of Pure and Applied Chemistry (IUPAC) might be considered as a support for this need. The purpose of the project is enhancing learners’ higher order thinking skills so that they can solve complex, interdisciplinary, real-world problems. Since system thinking exists in the conceptual framework of STEM education, chemistry education might be facilitated with practices of STEM education to contribute the development of higher order thinking skills of learners (York et al., 2019). Moreover, practices of laboratory skills like finding the suitable components for spectrophotometers in chemistry presents advanced context for STEM education (Shidiq et al., 2021). Therefore, the pre-service chemistry teachers’ conceptions of STEM education and practices of iSTEM provide a potential research area.

2.3 The Engineering Design Process (EDP) of STEM Education

Engineering discipline provides teaching and learning environment for integration of subjects of STEM disciplines by offering practitioners a chance of dealing with similar contexts from real-world (Honey, 2014). However, lineament of engineering, which is being a key for linkage of STEM disciplines, is more than providing real-life problems. Engineering education in STEM is not only about obtaining knowledge and practices of engineering, but also about promoting to realize engineering design and thinking (Next Generation Science Standards [NGSS], 2013). Integration of engineering design and thinking into the structure of the science is carried through the overlapping features in the processes of identifying problems and provide solutions (Bybee, 2011; NGSS, 2013), structure of the mathematics with usage of mathematical reasoning for developing suggestions to engineering problems (Akins & Burghardt, 2006), and structure of the technology with combination of engineering and technological design (Kwon & Park, 2009). Therefore, engineering design thinking and design process provides ground for integration of STEM disciplines (English, 2016; Hudson et al., 2014; Jung et al., 2023; Yata et al., 2020).

The importance of the engineering design process (EDP) in STEM integration cannot be denied so there is a need for detailed examination about meaning of the EDP expending from engineering design to the EDP. Although "problem solving" is an umbrella term for defining engineering design, bountiful definitions for it exist due to the highlighted aspects in the definitions. For example, Jung et al. (2023) have defined the EDP as identifying and solving real-world problems while Daugherty and Carter (2018) have adopted the broader perspective about problem solving by describing it as steps of design loop that contains considering core concepts, working under the criteria and constrains and setting plans and procedures. Moreover, there are definitions in which finding solutions for technology-based problems was seen as engineering design (Hill, 2006; International Technology Education Association, 2007; Katehi et al., 2009; Ullman, 2003, as cited in Gattie & Wicklein, 2007). On the other hand, definitions of engineering design emphasizing effect of the needs of the customer on the process of problem solving also exist (Dym et al., 2005; Guzey et al., 2016; Purzer & Quintana-Cifuentes, 2019).

Design is in conjunction with process since design ensued during the process of finding solution to the problem (Williams, 2000). Therefore, definition of engineering design and the EDP are not dichotomous terms instead they fulfill complementary needs of engineering. In other words, like engineering design, there are multiple definitions for the EDP. Defining of the EDP become more meaningful if it is based on the norms and practices set by NGSS (2013) because learning objectives of STEM disciplines were spread out the structure of the EDP and so there is a need of organization of these objectives. According to NGSS (2013), process of learning can be followed by three dimensions called as "science and engineering practices," "crosscutting concepts," and "disciplinary core ideas." "Science and engineering practices" is related with what professionals perform throughout their practices, "crosscutting concepts" provides insight about the connection between the science and engineering and "disciplinary core ideas" offer an opportunity for learners to possess knowledge beyond the formal school objectives. These dimensions diffuse all over the EDP and give specific value for each step of the process. In the light of these dimensions - specifically engineering core ideas - NGSS (2013) postulated three major steps for the EDP which are "defining and delimiting engineering problems," "designing solutions to engineering problems," and "optimizing the design solution" (p. 2). In the first step, problem is described based on the criteria and constraints. Then, in the second step, possible solutions to problem are suggested and the best solution was determined. At the final step, determined solution to problem is tested and redesigned if it is necessary.

Parallel to the general framework of the EDP was set by NGSS (2013), iterative process in which cyclical process of testing, evaluating, and re-designing keep going until reaching the desired qualifications is common aspect in all definitions (Arık & Topçu, 2020). In their studies, Dym et al. (2005) had proposed three phases of common aspects of the iterative the EDP that are analysis of problem, generating solution to the problem and evaluating the solutions. Although there are studies support the three phases for iterative process of engineering design (Ali & Tse, 2023; Dasgupta et al., 2018), there are plenty of the EDP models in the literature. To illustrate, as a member of NASA, Hoban and Delaney (2012) have developed activities about the teaching the EDP by using theme of investigations on Moon for middle school students. Design of the activities based on the steps of NASA engineers follow in their space mission. The steps of the EDP are (1) ask, (2) imagine, (3) plan, (4) create, (5) experiment & test and, (6) improve. After asking questions and imagine a solution for the problem, design should be planned for the solution. Then, plan is implemented to create a model. Experiments are conducted and model is tested. Finally, improvements are done on the model to reach the best solution. Without giving any guidelines for the "imagine" and "plan" steps, the application of the EDP of NASA on education gains specific feature.

Another model for the EDP was proposed by Massachusetts Department of Education (2006) via curriculum framework of science and technology/engineering. Their model consists of eight consecutive steps as shown in the Figure 2.1.

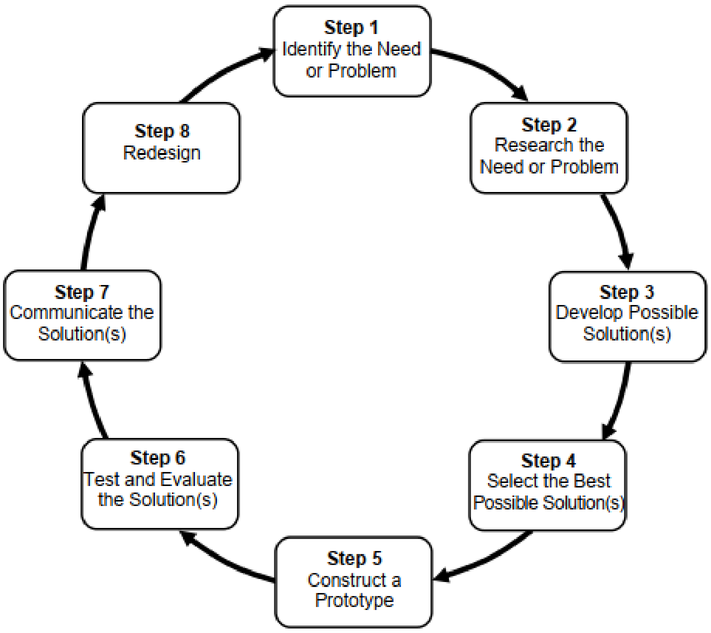

Figure 2.1 Steps of the EDP (Massachusetts Department of Education, 2006)

This model provides detailed explanations for each step which makes it useful guideline from preK-2 to high school for application of the EDP. For example, practicing of more advanced level of engineering skills was expected from students to solve engineering/technology problems with the knowledge of science and mathematics by following the steps of the EDP at high school level when compared to grades 6–8. Regardless of the grade level, however, successive steps of the engineering design start with the "identification of problem" and end up with "redesign".

At the first step, problem is identified by students via given opportunities like resources or tools. It is followed by "research the need or problem" step in which students make research about the current state of the problem and the existing solutions for it by using different sources. The third step of the model "develop possible solution(s)". This step of the model demands making brainstorming about possible solutions, stating them in two and three dimensions and rectify them by taking the advantages of science and mathematics. The fourth step is "select the best" in which the solution(s) that meets the requirements of problem is chosen. After best possible solution(s) is determined, model(s) of possible solution(s) is constructed. Then possible solution(s) is tested whether it works or not by meeting the design constraints at the step of "test and evaluate the solution(s)". When students come to "Step 7: Communicate the solution(s)", they make presentation about the how their solution(s) answers the problem by emphasizing the societal impact of their solution(s). Finally, at "redesign" step, students make amendments on their solution(s) according to the feedbacks that got from their presentations.

On the one hand extensive knowledge about the steps of the Massachusetts Department of Education (2006) model of the EDP presents to guideline easy to follow, on the other hand completing the cycle in restricted instruction time is compelling due to the requirements of "communicate the solution" (Step 7) and "redesign" (Step 8) steps in which problem/need is revisited and cycle is repeated (Li et al., 2015). Therefore, Hynes et al. (2011) have worked on the problems of the Massachusetts Department of Education (2006) model of the EDP, and asserted a model as shown in the Figure 2.2. All the steps of the model that Hynes et al. (2011) proposed same with the Massachusetts Department of Education (2006) model of the EDP, but they have inserted "completion decision" as a last step of the model. At the ninth step, it is expected from students to determine the qualifications of their possible solution meet the requirements of the problem/need sufficiently and present their final solution. Additionally, problems arising from the repetitive nature of "communicate the solution" (Step 7) and "redesign" (Step 8) steps was solved by addition of "completion decision" step because the "completion decision" step brought the model is the accepting believes of students about the adequacy of meeting the design criteria and constraints to finalize their product. Additionally, Hynes et al. (2011) claim that solution of real-life problems does not happen only in cyclic manner, so they contribute the model of The EDP Massachusetts Department of Education (2006) by adding the relationships from Step 1 to Step 8 in zig-zag pattern.

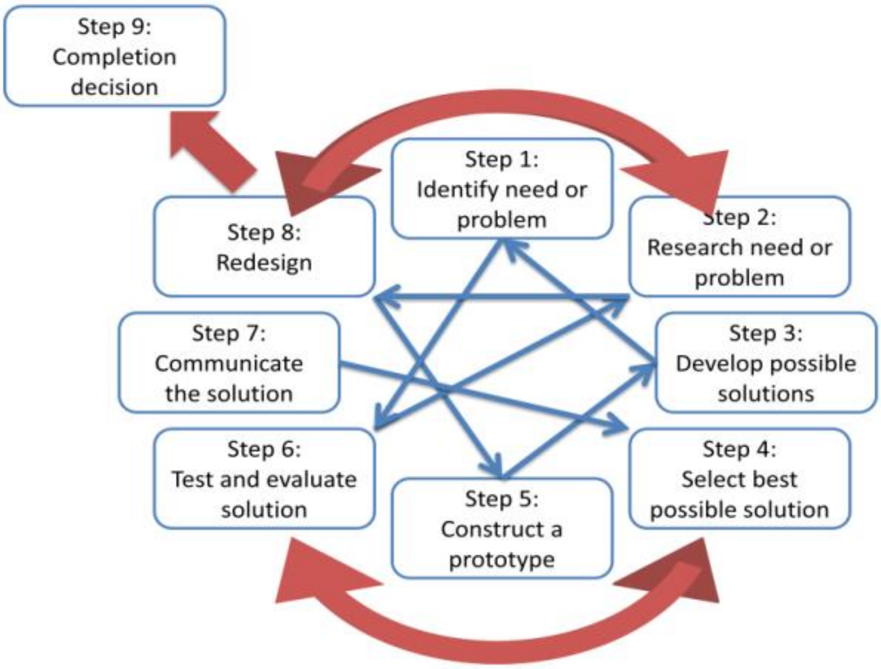

Figure 2.2 Steps of the EDP (Hynes et al., 2011)

Almost every model that has been proposed for implication of the EDP includes steps similar to Hynes et al. (Dym & Little, 2013; Farmer et al., 2012; Moore et al., 2014; National Research Council, 2012; Tien et al., 2020). Although the number of the steps and the terms that define these steps are varied, there are common points among them which are testing, evaluating, and redesigning the model so that fulling the criteria and constraints of planned design. According to Linh and Huong (2019), the model which proposed easily followed steps of the EDP surpass others. Because their model reflected the multi-stranded and iterative nature of design process by proposing task schedules of each step of the process, model of English and King (2015) was taken as reference for the EDP in the present study (Watkins et al., 2014). In their model, there are five steps that define the EDP which are “problem scoping”, “idea generation”, “design and construct”, “design evaluation”, and “redesign” (see Table 2.1).

Table 2.1 The EDP Model (English & King, 2015)

Problem Scoping	**Idea Generation**	**Design and Construct**	**Design Evaluation**	**Redesign**
Understanding the boundaries of a problem	Brainstorming and planning	Model development	Meeting constraints	Model redevelopment
- clarify and restate the goal - identifying constraints - consider problem feasibility drawing - add context - experiment with materials - establish collaboration	- share and formulate the ideas - discuss strategies - develop a plan	- sketch design - interpret design - transform design to model	- test model - check constraints - assess goal attainment	- review first design - sketch new design - transform design to revised model
STEM Content Knowledge				

English and King (2015) believe that scoping the problem is essential part of obtaining enhanced engineering design solutions. Therefore, they emphasized the importance of determining the boundaries to find effective solutions to real-world problems. Beside the boundaries of problem, they have also presented practices under the problem scoping which are “clarifying and restating the goal of the problem,” “identifying constraints” to fulfill the necessities of solution, “consider problem feasibility,” “add context” to make problem familiar and more meaningful, “experiment with materials” by discussing the features and “establish collaboration” while working on finding solution to problem. Idea generation part of the engineering design model of English and King (2015) is related to brainstorming of ideas and making planning for solution of problem. Idea generation of the EDP is realized with collaborative teamwork in which ideas are explained as “share and formulate the ideas,” arguments are justified and criticized as “discussing strategies” and understanding of solution is developed as “development of plan”. These three processes also continue throughout the remaining processes of engineering design model.

Design and construct part focus on model development that consists of sketching and interpreting of design and transforming it into a model. Sketching of the design is the key component of the engineering design model of English and King (2015) since they have asserted the positive effect of design sketches on design outcome in a way of showing criteria and constraints of problem situation were satisfied or not and reserving possible solutions. Design evaluation contains “test model,” “check constrains,” and “assess goal attainment”. After design sketching was completed and primary model development has performed, model is tested based on the constraints specified initially. Required adjustments on the initial model is actualized at the redesign part with model redevelopment. Transformation of the primary model happens by flowing the processes of “review first design,” “sketch new design,” and “transform design to revised model.” By the help of examinations of design sketches, optimization of the primary model with the purpose of meeting the constrains has practiced.

This the EDP model stood out from the rest of the models for this study not only having a smaller number of steps for defining the process but also detailed and clear explanations of these steps by categorizing them as themes and sub-themes. Moreover, the most prominent feature that distinguishes this model from others is the approaching STEM content knowledge as key factor to solve engineering problems since as well as the core content knowledge of science, technology, engineering, and mathematics, interdisciplinary application of these disciplines is important for advancing STEM integration (English, 2016).

In their studies Tank et al. (2018) claimed that usage of direct terms for steps of the EDP makes the process more understandable for learners. Moore et al. (2014) had simplified the nomenclature of the EDP of English and King (2015) by using the "ask", "imagine", "plan" and "create", as names for "problem scoping", "idea generation", "design & construct" respectively and "test" and "improve" for "design evaluation" and "redesign" processes. Although names of the steps of the EDP are different, descriptions of the model of Moore et al. (2014) and model of English and King (2015) are almost similar (Ali & Tse, 2023).

Overall, there seems to be some evidence to indicate that although there is not a common definition of the EDP in STEM education, its importance for integration of STEM disciplines and for learners to obtain deeper understanding with active engagement of STEM disciplines (Turner et al., 2016; Williams et al., 2008) are the building blocks of the EDP definitions in STEM education.

2.3.1 Studies About the EDP of STEM Education

There is a large body of studies that pay attention to the role of engineering-based activities on pre-service teachers' conceptualization of STEM. Some of these studies are related to the thoughts and perceptions of pre-service teachers about practices of engineering-based STEM education. For example, detailed examination of engineering-based STEM approach views of elementary pre-service teachers by Maiorca et al. (2023) showed that elementary pre-service teachers' views about the importance of STEM education and their knowledge about its applicability have been enhanced after they have employed engineering to teach science and mathematics concepts with model-eliciting activities. A total of seventeen elementary pre-service teachers from the different part of the United States have joined the online teaching method classes in which they took part in three model-eliciting activities and designed one activity by themselves at the end of the course. Data were collected from class assignments in which participants of the study also wrote their reflections about model-eliciting activities engineering-based integrated STEM learning before and after the method courses. After data were coded based on the equity-oriented STEM literacy framework, they concluded that elementary pre-service teachers had developed positive perception about using the EDP for integrated STEM education by the help of the model-eliciting activities. In another study, Widiastuti et al. (2020) argued the understanding of pre-service teachers about the EDP in integrated STEM education. They have worked with twenty-eight pre-service science teachers who are knowledgeable about STEM and collected the data from them by using survey as a data collection tool. Items of the survey assessed participants' general understanding, knowledge, and conceptions of integrated STEM education and the EDP. Unlike investigation of Maiorca and coworkers, result of this study showed that most of the participants defined STEM as an integration of science, mathematics, engineering, and technology whereas they did not possess the information about how the integration can be succeeded. Moreover, participants of this study did not express some conceptions of integrated STEM education like connection between the subjects of core disciplines and overlapping disciplines as well as they did not put emphasize in engineering for integration of STEM disciplines.

In addition to the studies that examine thoughts and perceptions of pre-service teachers about practices of engineering-based STEM education (Karisan et al., 2019; Kilty & Burrows, 2019; Meyer & Parker, 2021; Özkizilcik & Cebesoy, 2023), there are also studies that examine the role of the EDP on knowledge about the practices and conceptions of STEM education (Bachnak et al.,2014; Kuvac & Koc,2023; Mumba et al., 2022; Shahat et al., 2023). As noted by Lin et al. (2021), when project-based STEM approach accompanied by the EDP, engineering design thinking of technology pre-service teachers has improved. In their study, Lin and coworkers has studied with twenty-eight technology pre-service teachers and have collected data by using pretest-posttest nonequivalent groups design. Following enhancing STEM knowledge of participants about the mousetrap car activity by giving the related information from core disciplines, designing the mousetrap car was demanded. Results of their study showed that participants of the experimental group in which problem-based curriculum based on the EDP was implemented were different than control group in terms of identifying problem, producing ideas, modelling, and feasibility analysis parts of the design thinking. In the same vein, Aydeniz and Bilican (2018) have conducted a study with pre-service primary teachers to dissect their STEM concepts and knowledge about STEM pedagogy. They have worked with twenty pre-service primary teachers who have no experience about STEM related contents. Participants of the study has taken the workshops from the engineers and gained practical and theoretical knowledge about the EDP. After that, participants performed three engineering-based STEM activities. Data have been collected throughout the EDP experience by using questionnaires, interviews, and reflection papers. Analysis of data revealed that participants' content knowledge about STEM, pedagogy knowledge about iSTEM, and knowledge and application of the EDP has developed thanks to iSTEM activities that they have experienced.

Along with the studies that has been mentioned, there are some authors have specifically been interested in the pre-service chemistry teachers' knowledge and conceptions of engineering-based STEM education. The study of STEM conceptions of the pre-service chemistry teachers was carried out by Aydın-Günbatar et al. (2021). Throughout the thirteen weeks period of the study, the pre-service chemistry teachers were trained to be qualified in integrated STEM education by learning different types of integrated STEM education, performing activities, and designing and evaluating lesson plans. Data were collected by using "STEM Reflection Protocol" in which participants draw and explain their model of STEM integration. The results revealed that STEM conceptions of the pre-service chemistry teachers about usage of the EDP both as context and linkage of integration of discipline have enhanced predominantly. This view is supported by

Ambroz et al. (2023) who stated that engineering in STEM education can be put forward if projects were implemented in a manner of system like engineers have adopted by synthesizing, evaluating, and converting design into product. Researchers brought this idea in master level of chemistry course of the pre-service chemistry teachers to construct a tool that measure the heat transfer with the help of technological programs. After participants were informed about basic concepts, they practice the the EDP and produce three-dimensional model of their design. Data were collected during the course and examined by using inductive content analysis. Results of the research have shown that by using technological tools and engineering approach, both chemistry-driven STEM education and place of engineering in STEM education can be promoted.

Overall, there seems to be some evidence to indicate that understanding and knowledge of pre-service teachers about the EDP is important to promote STEM integration and its application in the future classroom settings. Therefore, investigation to reveal the pre-service chemistry teachers' conceptions will promise to give dimensions of the engineering design-based instruction due to the limited number of studies specific to chemistry subjects.

Beside the conceptions of the pre-service chemistry teachers about engineering design-based instruction, investigating the role of the EDP on adoption of self-regulation by the pre-service chemistry teachers also sheds light on the cognitive territory of the EDP. Since overarching theme of engineering design-based instruction is practicing multidimensional activities of the integration of STEM disciplines, importance of adoption of self-regulation becomes evident to get through these activities (Hwang et al., 2020). Therefore, the next section was devoted to literature about self-regulation and engineering design-based instruction.

2.4 Social Cognitive Theory and Self Regulation

Human development can be categorized as physical, personal, cognitive, and social development. For example, cognitive development is related to change in thinking while social development is based on changes in social interactions (Woolfolk et al., 2003). Learning is connected with human development. Since human development emerges in varied forms, there are different theories about the individuals' way of learning due to the different observations, knowledge, experiences, and beliefs of the people working in that field (Wang, 2012). The social cognitive theory is one of the learning theories that hypothesizes on learning and behavioral performance of individuals (Schunk, 2012). The social cognitive theory was evolved from the social learning theory which concerned with how learning happens through observing others (Devi et al., 2016). Earlier studies about the social learning theory have set forth by Bandura (1971) who claimed that modeling plays an important role in learning. He has explained the modeling with four subprocesses starting with noticing the distinctive characteristics of model's behavior (attentional process), modeling the behavior in one time to other with the help of symbolic representations (retention process), behavioral reproduction of symbolic representations of modeled behavior (motoric reproduction process) and providing positive incentives to maintain the modeled behavior (reinforcement and motivational process). Since Social Learning Theory has deprive learning processes of cognitive processes like outcome expectations or feelings, Bandura has overhaul Social Learning Theory to Social Cognitive Theory (Bandura, 1986). The social cognitive theory of Bandura asserted that the behaviors of individuals are sensitive to cognition as well as environmental/social factors of learning (Bandura,1986). The relationship between these factors is explained with Triadic Reciprocal Determinism Model in which the mutual interactions between personal, behavioral, and social/environmental factors are demonstrated by using "determinism" as a term to emphasize the occurrence of effects with events instead of serious of causes (Bandura, 1978). As seen in the Figure 2.3, Triadic Reciprocal

Determinism Model demonstrates the effect of personal factors and environment on behavior that in turn might change the environment and personal influence of individuals (Schunk & DiBenedetto, 2023).

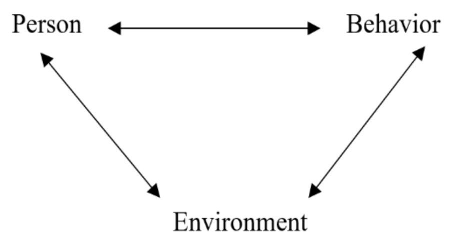

Figure 2.3 Triadic Reciprocality Model of Causality
(Bandura, 1986, p.24)

It is important to note that phenomena such as self-efficacy, outcome expectations, values, and attributions are associated with personal processes while instruction, social models, feedback, and rewards correspond to environmental processes and choice of activities, effort, achievement, and persistence are related with the behavioral processes (Bandura, 1986; Schunk & DiBenedetto, 2020). To identify the seeds for gaining view about Triadic Reciprocal Determinism Model, understanding of interaction between these processes is substantial. In accordance with this purpose, interactions can be clarified by using the example of Woodcock & Tournaki (2023) that is interest of student in drawing is personal factor; praise, and acceptance of her by teacher and other students in art class is environmental factor; and student's effort to make better drawing is behavioral factor. However, it should be taken into consideration these three factors do not always have equal weight in the model, one factor might ahead of others because of the amendments to environment or/and change in behaviors and personal factors (Schiavo et al., 2019).

From the point of human agency, interaction between environmental, behavioral, and personal processes can be categorized as emergent interactive agency that means human functioning is designated with interdependent behavioral, personal, and environmental factors as introduced in the social cognitive theory (Bandura, 1989). In other words, instead of mechanical or autonomous agency that only emphasizes either environment or cognitive factors respectively, the varying role of environment and behaviors on the performance of individual in particular activities were taken as an approach (Ponton & Rhea, 2006). All of the behavioral, personal, and environmental factors indicate the control of individual on learning process (Bandura, 2000). According to the social cognitive theory, capacity of humans to control these based on the cognitive mechanisms like self-directedness (Bandura, 1991). In other words, individuals have control on how to perform their learning processes depending on their own attainments of the learning goals with respect to their self-regulative capacities (Bandura, 1986).

Control of individual on own learning process is closely related to self-regulation that has defined as "self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals" (Zimmerman, 2000, p.14). There are different self-regulation models based on the approaches of how process of self-regulation is actualized by individuals. For example, Winne and Hadwin (1998) have proposed a model by advocating the metacognitive perspective in which self-regulated learners were described as active while Pintrich (2000) has put emphasize the relationship between motivation and self-regulated learning (Panadero, 2017). Among the models from literature, cyclical model of self-regulation proposed by Zimmerman (2000) was chosen as a framework to understand the self-regulation adoption of the pre-service chemistry teachers for the present study since cyclical model provides details about the processes under the forethought, performance and self-reflection phases that makes easy to detect the aspect related to learning experience (Panadero & Tapia, 2014). Therefore, in the following section, phases of cyclical model of self-regulation (Zimmerman, 2000) will be explained.

2.4.1 Cylical Model of Self-Regulation

To understand the Zimmerman's cyclical model of self-regulation (2000), his former model of self-regulation should be demonstrated due to the progressive nature of his self-regulation models.

In his primary model (see Figure 2.4), Zimmerman (1989) has described the self-regulation by referring the Triadic Reciprocal Determinism Model of Bandura (1986). Triadic view of self-regulation underline that self-regulated learning is easily affected from differences in contexts and personal experiences. As seen in the Figure 2.4, to develop the regulatory influence of person (self-) processes, strategies for controlling the behavior, environment, or covert processes can be applied. Firstly, behavioral self-regulation is related with the application of a self-evaluation strategies by using enactive feedback. Secondly, environmental self-regulation is usage of strategies to manipulate the environment under the condition that environmental self-regulation strategies should be performed according to key personal processes. Finally, covert self-regulation proposes that covert processes like adapting thoughts or/and feelings of individual affect reciprocally each other and usage of covert process strategies can be regulated reciprocally by the help of covert feedback loop.

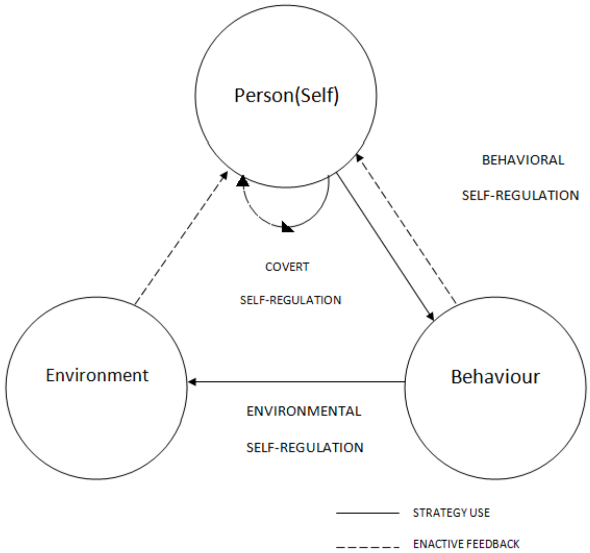

Figure 2.4 Triadic Analysis of Self-regulated functioning
(Zimmerman, 1989, p. 330)

After his primary model that focuses on reciprocal relationship between the self-regulation and environment and behaviors, Zimmerman (2000) has asserted the self-regulation model (see Figure 2.5) that built on cyclical phases of self-regulation processes and their accompanying beliefs depending on the social cognitive theory. He categorized three cyclical phases as forethought, performance or volitional control, and self-reflection processes with their subprocesses as seen in the Table 2.2. Forethought phase is the stage in which ignition of wick about whether act of learning possessed or not is determined. Performance or volitional control phase covers the processes that influence the attention and implication on task during the learning. Self-reflection phase includes the processes about the judgements about the learning experience after performing task. Depending on the self-reflections on learning experience, self-regulatory cycle can be finalized or started over again.

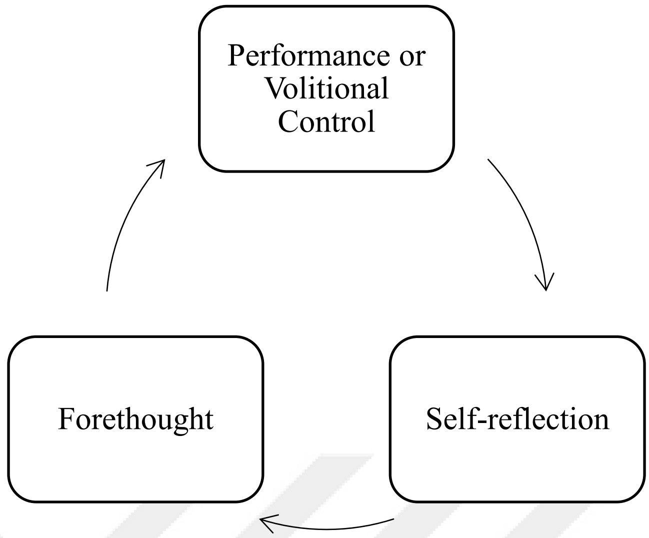

Figure 2.5 Cyclical Model of Self-regulation (Zimmerman, 2000, p. 16)

Table 2.2 Cyclical Model of Self-regulation (Zimmerman, 2000, p. 16)

CYCLICAL SELF-REGULATORY PHASES		
Forethought Phase	Performance/Volitional Control Phase	Self-reflection Phase
Task Analysis	**Self-control**	**Self-judgement**
Goal setting	Self-instruction	Self-evaluation
Strategic planning	Imagery	Causal attribution
	Attention focusing	
Self-motivation Beliefs	Task strategies	**Self-reaction**
Self-efficacy		Self-satisfaction/affect
Outcome expectations	**Self-observation**	Adaptive-defensive
Intrinsic interest/ value	Self-recording	
Goal orientation	Self-experimentation	

The phases of cyclical model of self-regulation (Zimmerman, 2000) are explained in detail below:

Forethought Phase

As an initial phase of cyclical model of self-regulation (Zimmerman, 2000), it is the period that individuals examine the task according to their competencies before working on it. There are two main subprocesses of forethought phase which are "task analysis" and "self-motivation beliefs". While task analysis includes goal setting and strategic planning, self-motivation beliefs is comprised of self-efficacy, outcome expectations, intrinsic interest/value, and goal orientation. First component of task analysis that is goal setting was defined by Locke and Latham (1991) as "the goal defines for the person what constitutes an acceptable level of performance" by indicating the goal setting enables self-regulation (p. 234). Individuals who possess the high level of self-regulation have hierarchical goal systems. In this system, process goals are seen as proximal regulators to outcome goals for both degree of approximation to outcome goal mechanically and progression towards outcome goal personally. Second component of task analysis is strategic planning. It is related to having task specific methods to reach the optimum performance of the skill. Strategic planning is not static in nature that is it requires adjustments according to personal, environmental, and behavioral factors. Overall, self-regulated individuals review their goals and strategies before experiencing the task to make arrangements regarding to characteristics of given task. Self-motivation beliefs hold an important position for applying the goal setting and strategic planning as well as actualizing the experience of task. Self-efficacy is one of the self-motivational beliefs. It is defined as individuals' beliefs about their personal capability to achieve a specific task (Bandura, 1997). There is a reciprocal relationship between the self-efficacy and goal setting (Zimmerman, 2000). Self-regulated individuals have hierarchical goal systems, and they focus on personal progress as well as mechanical progress. Since they have personal goals about progression, satisfaction about success of reaching the goals are attained before reaching the ultimate goal of task. As a result of having personal goals about progression, individuals feel themselves self-efficacious.

There is another self-motivational belief that is outcome expectations. It places reliance on the beliefs about highest level of finalizing performance (Bandura, 1997). Different than the self-efficacy belief, focal point of outcome expectation is final expectations (Zimmerman, 2000). The process of self-motivation beliefs also contains goal orientation. Goal orientation is defined by Pintrich (2000) as purposes of individuals for doing task. He indicated that there are two general goal orientations about the purposes and reasons of individuals for engaging in a task. In the literature, different models exist to explain these two goal orientations. To illustrate, in the goal orientation model of Dweck and Leggett (1988; as cited in Pintrich, 2000), they have named these goals as learning and performance goals. Learning goals refer to enhancement of competence and performance goals are related with the adopting the affirmative judgments of competence. Another model that propounded by Ames (1992) in that two goal orientations were labelled as mastery and performance goals. She categorized the learners as mastery goals orient if they are "developing new skills, trying to understand their work, improving their level of competence, or achieving a sense of mastery based on self-referenced standards" (p. 262). On the other hand, she defined the learners as performance goals orient if learners give their attention to their ability and self-worth that was determined based on the surpassing others. In addition to self-efficacy, outcome expectations, and goal orientation, intrinsic interest/value takes place as a sub-process of self-motivation beliefs. Intrinsic interest is described as the degree of individuals' engagement of the task regarding to their innate curiosity and interest (Pintrich & De Groot, 1990). Intrinsic interest/value is interwoven with goal orientation since goal orientation shifts from outcome rewards to intrinsic values when mastery skills were gained by individual. To sum up, self-motivation beliefs play an important role for deciding the performing task and the strategies attained to perform it.

Performance or Volitional Control Phase

Performance phase consists of the processes that are implemented while individuals experience the task. There are two main processes in this phase which are self-control and self-observation. The subprocesses that are administered with the purpose of helping to focus on task and optimize the effort to perform it are categorized under the self-control process. Self-instruction is one of these subprocesses that means conceiving discriminative stimuli so that self-regulatory responses resulting in reinforcement can be evolved (Mace et al., 1989, as cited in Schunk, 2012). Self-instruction involves overt or covert description of performed task by individual (Zimmermann, 2000). In his study Schunk (1986) also emphasized the role of verbalization (as an overt description) to improve the self-regulation. Imagery is another subprocess for self-control process. Individual’s generation of mental pictures like mental visualizing the movements applied successfully in the physical education make huge contribution to motor performance and development of task related skills (Anderson, 2013). Self-control process also involves attention focusing that is related with enhancing individual’s concentration on overt or covert processes (Zimmerman, 2000). Affective techniques like self-verbalization are helpful for maintaining attention and concentration on tasks (Schunk, 2012). Last subprocess related with the self-control process is task strategies. Execution of task strategies implies dividing given task into its key components and then reorganizing them in meaningful way (Zimmermann, 2000). Summarizing each section in the text, taking notes, underlining, grouping the learned items can be given as some examples of task strategies (Weinstein & Mayer, 1986). Self-observation process is monitoring the individual’s own performance on task and the conditions that the task is performed. Self-observation process includes self-recording and self-experimentation. Self-recording is beneficial to keep tracking the frequency of the actions done while experiencing the task through while self-experimentation is important to gain better personal understanding and performance since it enables to conclusive diagnostic evidence about the behaviors that cannot be explained in natural setting (Zimmerman, 2000).

Self-Reflection Phase

After task is completed, evaluation of the performance is carried through the self-judgement and self-reaction processes that are categorized under the self-reflection phase (Zimmerman, 2000). Process of self-judgement is actualized to assess the task performance and the reasons behind this performance by the performers with the help of self-evaluation and causal attribution subprocesses. Self-evaluation can be described as comparison of performance of individual based on the criteria. There are four types of criteria that individual can exert to evaluate her performance that are mastery, previous performance, normative, and collaborative. When mastery is used as criterion, individual evaluate the performance in the scale ranging from novice to expert. On the other hand, previous performance criterion is related with the comparison of individual her actual performance with the previous performances. However, normative criterion is based on the evaluation of performance by comparing the other's performance rather than herself. Differently, collaborative criterion requires the comparing the performance of the individual depending on how well position on the team is fulfilled. Causal attributions are correlated with the how individuals evaluate themselves since causal attributions seek for the meaning of the success or failure in performance. For example, the doctor who has diagnosed the rare disease in her patient can attribute this achievement her training, intelligent or luck and the one who cannot diagnose can attribute the lack of skills (Harvey & Martinko, n.d.). By promoting motivation or regression about task, attributions have an impact on whether task is performed or not as well as how it will be performed. Since individuals' attributions have an effect on performing task, there is a cognitive and affective reactions toward task that is named as self-reaction (Panadero & Tapia, 2014). Self-reaction contains self-satisfaction/affect and adaptive/defensive decisions subprocesses. Self-satisfaction is related with the personal satisfaction and dissatisfaction concepts of individuals and effect of these personal concepts on their task performance (Zimmermann, 2000). Pintrich (2000) has underlined the importance of self-satisfaction by indicating the following or drawing back behaviors toward performance of task. On the other hand, adaptive/defensive decisions subprocesses are related to the alterations that should be made on self-regulation processes to perform the task better in the future (Zimmerman, 2000). While adaptive decision strategies like proximal goal setting (Wolters, 2003) is defined as enthusiasm to perform the task again and promote implication of better self-regulation strategies (Zimmerman, 2000); defensive decisions strategies like procrastination (Wolters, 2003) are defined as avoiding to perform task again executed by individuals to eliminate the risk of dissatisfaction (Zimmerman, 2000). Altogether, self-reaction processes have an impact on cyclical phases of self-regulation since they directly affect the strategies in forethought phase in terms of deciding the performing of task (Zimmerman, 2000).

2.4.2 Studies about STEM Education and Self-regulation

A considerable amount of literature related to STEM education and self-regulation has been published. One of these studies was conducted by Blackmore et al. (2021) who had reviewed the literature about the usage of self-regulated learning strategies for the enhancements of STEM learning. They have focused on maintaining the successful academic performance of the undergraduate students of STEM disciplines from high school to university. After searching for the strategies of fixing the poor self-regulation cycle and improving it for better academic performance, they concluded that improvements on learning and academic performance of STEM for undergraduate students can be expected as a result of implementation of meta-learning activities and interventions of self-regulated learning cycle.

There are also studies that had revealed the self-regulation level of students from STEM fields. For example, Abun and Magallanes (2018) have investigated the level of self-regulation and its effect on academic performance by working with the 302 STEM senior high school students. Data were collected by the help of the questionnaires to measure the aspects of the self-regulation as well as the academic performance. There are four measured aspects of self-regulation external regulation (act of behavior is externally motivated), introjected regulation (act of behavior is arisen from the avoidance of failure as a result of internalizing the external stimulus), identified regulation (act of consciously accepted behavior to reach the self-valued outcome) and intrinsic motivation. The result of the study showed that external, introjected and identified regulation of most of the students are high while intrinsic motivation is moderate and there is no correlation between self-regulation and academic performance. On the contrary the study of Abun and Magallanes (2018), in an investigation of relationship between STEM and self-regulation, Kanjanapan et al. (2021) found that learning subjects with STEM education increases both self-regulation and achievements of students. Kanjanapan et al. (2021) have compared the 10th and 11th grade science and mathematics students' self-regulation before and after the performing problem-based STEM project that aims to develop the achievement of the students about of sustainable development goals. Beside the self-regulation scale and researchers' notes, STEM lesson plans based on 5E method were used as data collection tools. The result of the study indicated that learning sustainable development goals with STEM context increased the self-regulation of students.

Similarly, in their study Shell et al. (2013) propound the importance of motivation and strategic self-regulation to become successful in STEM courses. They have worked with 175 university students who enrolled in computer science course and collected the data by implementing Likert scale instrument for strategic self-regulation in which five items were used to measure the scope of planning, goal setting, monitoring, and evaluating of studying and learning of participants. The results have revealed that students' knowledge of course content and course achievement are closely related with the classic cognitive and metacognitive self-regulation. Another study that was conducted by Gumilang et al. (2022) has underline the benefits of execution of self-regulated learning based on STEM education to enhance the self-directed learning. By collecting data from 54 physical education department students which were divided as control and experimental group depending on taking self-regulated learning based on STEM education and analyzing them according to the tenets of awareness, learning strategies, learning activities, evaluations, and interpersonal skills results were obtained. The study showed that participants who were expose to of self-regulated learning based on STEM education are better in their time management skills, control over thinking, planning, implementing, and evaluating learning strategies when pre-test and post-test results were compared.

Collectively, these studies outline that self-regulation and STEM education are closely related to each other. STEM education has an impact on self-regulation of students and implementation of self-regulation processes on STEM education gives better results for performance of students. However, there is a need of investigation about the self-regulation level of undergraduate students from teacher education programs since teachers will raise the workforce for STEM fields. Furthermore, there is a need of deeper comprehension for relationship between the self-regulation and STEM education to go beyond the rule of thumb for understanding the mechanism of STEM disciplines. Therefore, next section focuses on the engineering discipline from STEM education and its relationship with self-regulation.

2.5 The EDP of STEM Education and Self- regulation

The International Technology and Engineering Educators Association (ITEEA, 2020) has set the standards for engineering literacy by putting the design at the core of it. According to the NSF funded project of the ITEEA, engineering design is a purposeful, creative, and iterative activity that based on ill-defined questions with criteria and constrains. They also asserted that there is no single design solution, and the solution has a potential for improvement or refinement (ITEEA, 2000). Although there are various models for implementation of engineering design, common points of these models agree on its iterative and weakly sequential nature to find a solution to presented problem (Sung & Kelly, 2022). Because of the nature of engineering design, the outcomes of the former stages can induce adjustments in the current solution of the problem. Making these adjustments requires not only usage of knowledge and skills about the subject but also appropriate self-regulating strategies to be able reach the successful solution because like engineering design, self-regulation is an active and iterative process (Lawanto et al 2013; Pintrich, 2000).

There are studies in the literature that propound the models which relate the process of engineering design with phases or/and processes of self-regulation. One study by Zheng et al. (2020) examined the self-regulated learning in engineering design and developed a model (see Figure 2.6). Their model sets forth the embeddedness of design knowledge and design process by proposing the structural, functional, and behavioral knowledge as three types of knowledge which are correlated with the design processes of observation, formulation, reformulation, analysis, and evaluation.

Specifically, design processes are covered under the cognition part of the model that refers to self-regulated learning components of forethought, performance, and self-evaluation to present relationship between the phases of self-regulation and design process. Iterative nature of the phases was also showed by using the arrows. In their model, forethought phase is correlated with the observation part of design process in which individuals perform observations to comprehend the task and design processes of formulation, reformulation, and analysis are maintained by individuals correspond to performance phase while evaluation of design with respect to design requirements is covered under the self-reflection phase.

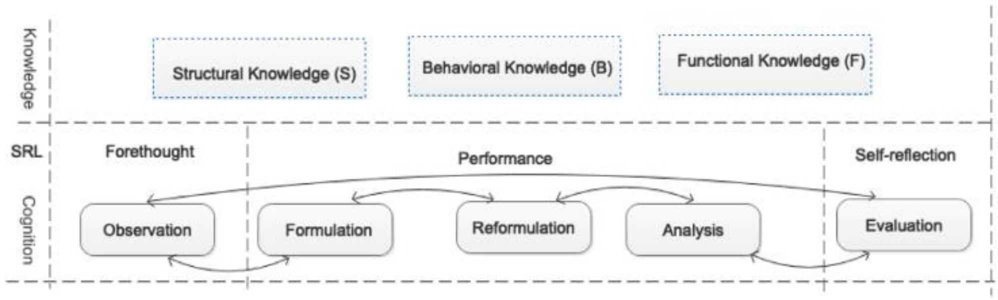

Figure 2.6 Self-regulation in Engineering Design (Zheng et al., 2020, p. 3)

Zheng et al.'s (2020) work on development of model which brings the self-regulation and the EDP is complemented by Li et al. (2020). They (2020) have constructed a self-regulated learning model in engineering design by taking the model of Zheng et al. (2020) and Zimmerman's cyclical model of self-regulation (2000) as reference. Differently, in addition to the self-regulated learning phases (forethought, performance, and self-reflection) and self-regulated behaviors (observation, formulation, analysis, reformulation, and evaluation), behavior attributes (information interpreting, preliminary design, prototype analysis, detailed design, and reflective thinking) were added to the model for tracking the task progress of individuals (see Figure 2.7).

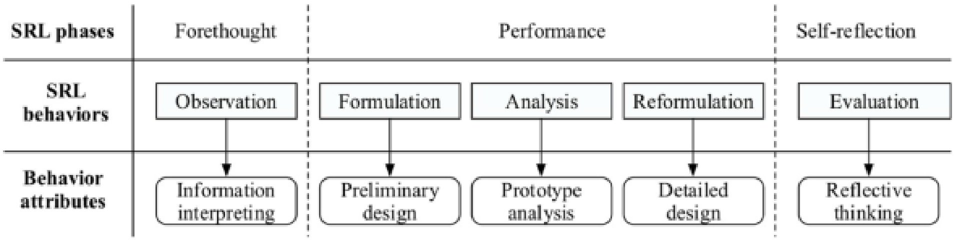

Figure 2.7 Self-regulation in Engineering Design (Li et al., 2020, p. 3)

In 2023, Zheng et al. published a model in which they emphasized the natural relationship between the self-regulation phases and design process by elaborating them in concentric pattern. Different than their previous model (Zheng et al., 2020), this model which is depicted in Figure 2.8 is broadening the scope of self-regulation process in terms of balancing its generalizability and authenticity by placing it into the context of the EDP without damaging its domain-specificity.

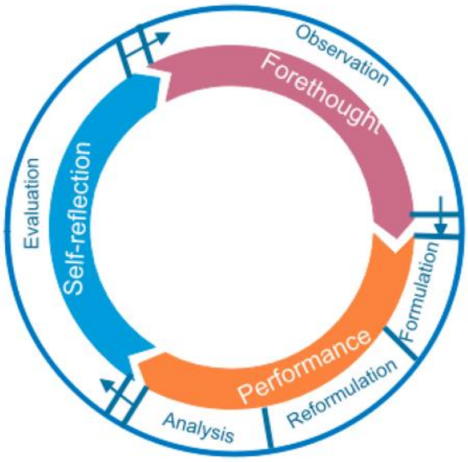

Figure 2.8 Self-regulation in Engineering Design (Zheng et al., 2023, p. 89)

2.5.1 Studies About the EDP of STEM Education and Self- regulation

Over the past decade most research in the EDP in STEM education has accompanied with self-regulation processes. In their article, Lawanto et al. (2013) identified the how students describe task, plan, and implement self-regulated learning strategies in design activity. A total of twenty-nine high school students from architectural design and robotics design classes were selected as participants. The aim their study is investigating the reflection of task interpretation levels of participants on usage of self-regulation strategies throughout design process and the effect of design-performing students' achievement on task interpretation and usage of self-regulation strategies. Different design activities were given to participants according to enrollment on architectural design and robotics design classes. Analysis of data were performed by using self-regulation survey for engineering and web-based engineering design notebook. The survey was implemented in three stages to indicate task interpretation and planning strategies at the beginning, cognitive strategies and monitoring/fix up at the middle, and criteria for performance at the final stage of design task activities. Web-based engineering design notebook was used as design journals to clarify the self-regulation strategies used by the participants in the phases of design process. Results indicate that there is tendency toward understanding the task requirements more than planning appropriate actions, choosing suitable strategies, and monitoring during task. Students who performed design activities have higher scores on cognitive and monitoring/fix-up strategies while others have higher score on planning strategies. Overall, the result of the study underlines the importance of self-regulation in design task by showing the role of task interpretation and implementing proper strategies for achieve suitable design. The studies about the EDP and self-regulation were extended by working with engineering students to investigate their self-regulated learning skills. Lawanto et al. (2017) grouped the fifty-seven engineering students who took web-intensive engineering course and compare their usage of self-regulated learning skills through goal setting, environment structuring, task strategies, time management, help seeking, and self-evaluation activities. Data were collected from online self-regulated learning questionnaire, data logs of the course like the frequency of accessing the course materials, ranking questions for evaluation of learning system and performance of students on final project of the course. Result of the study indicate that students who show the higher achievement on the final project of the course have higher scores on environmental structuring and goal setting that plays crucial role on task achievement.

Additionally, there are studies that declared the relationship between the EDP and self-regulation by exposing the models for self-regulation processes in engineering design. For example, Zheng et al. (2020) have investigated the occurrence of behavioral groups that evolved during the process of engineering design based on the self-regulation qualifications and examined the role of self-regulation qualifications on learning of the EDP. A total of 108 nineth grade students were chosen as sample to perform engineering design in simulated environment. Data were collected by using pre-test and post-test for measuring their scientific knowledge, motivated learning strategies questionnaire (MSLQ) for measuring their self-regulation characteristics, and computer log files to understand the type of knowledge used to perform the EDP that connected with self-regulated learning model. Based on their analysis, they have grouped the participants as competent, cognitive-oriented, reflective-oriented, and minimally self-regulated learners and examined their perceived self-regulation, learning gains and task performance. Results of their study show that, most self-regulated learners according to perceived self-regulation and those with the highest learning gains were competent self-regulated learners and they evaluate themselves to gain required knowledge successfully. Cognitive-oriented self-regulated learners' perception about themselves and task performance were as being the worst although they were second best while minimally self-regulated learners showed overestimation about their performance and learning gain although they were lowest ranking participants. On the other hand, reflective learners were the ones who oriented the result of the task have the best performance on the task.

Similarly, Li et al. (2020) conducted research about students' level of self-regulation behaviors during the EDP and effect of these behaviors on design performance. In their study, 102 nineth grade students have chosen as participants which performed the EDP by using simulation-based computer-aided design environment. Data have been collected by using specific science knowledge test, open-ended questions for design completeness and log files for design efficiency depending on time consumption and self-regulation level of participants. Analysis of data revealed that design performance of participants changes based on self-regulated learner characteristics that are reflective-oriented, adaptive, and minimally self-regulated. Among these self-regulated learner characteristics adaptive self-regulated learners are the ones who possess the best design completeness and reflective-oriented self-regulated learners have performed the design fast, so they displayed highest design efficiency.

Although there are studies that focused on the engineering design tasks from the pre-service teachers' perspective, these studies did not concern the usage of self-regulation processes during the EDP (Capobianco et al., 2021; Yuan et al., 2022; Zhu et al., 2023). Therefore, the present study will make a contribution to literature about the EDP of STEM education not only providing the information about the pre-service chemistry teachers' conceptions about it but also their adoption of self-regulation throughout the process of engineering design. Moreover, there are studies which stated the aspects of self-regulation under the categories of cognitive, metacognitive, and motivational processes and found that implementation of problem solving, collaborative learning, and inquiry-based learning enhanced all these aspects (Schraw & Hartley, 2006; Pionera et al., 2020). This study contributes to the literature by presenting engineering design-based instruction and its role of adoption of self-regulation processes by the pre-service chemistry teachers.

2.5.2 The Present Study

The studies presented thus far have the potential to provide evidence that self-regulation phases and the steps of the EDP are related to each other. In these studies, self-regulation model of Zimmerman (2000) and steps of the observation, formulation, reformulation, analysis, and evaluation of the EDP are taken as reference (Li et al., 2020; Zheng et al., 2020, 2023). However, in the present study, self-regulation processes based on the cyclical self-regulation model of Zimmerman (2000) throughout the EDP model of English and King (2015) and Moore et al. (2014) were examined because of direct and clear explanations about what expected of each step of process.

Figure 2.9 shows how each step of the EDP (English & King, 2015; Moore et al., 2014) is correlated with self-regulation phases (Zimmerman, 2000) in the present study.

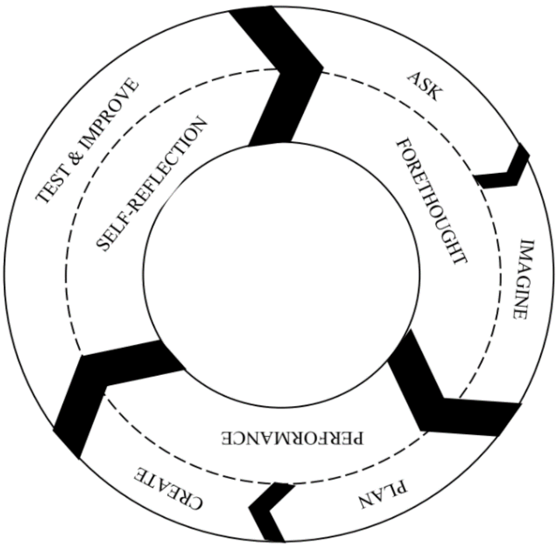

Figure 2.9 Combination of Self-regulation Phases of Zimmerman (2000) and Engineering Design Models of English & King (2015) and Moore et al. (2014)

The model that is presented in the Figure 2.9 reflects the nature of the phases of self-regulation and steps of the EDP by virtue of its cyclical form. In addition to this, the arrows in the model represent the consecutiveness of the phases of self-regulation and steps of the EDP. Since after engineering design-based instruction was implemented, adoption of self-regulation by participants was investigated in this study, the steps of the EDP were located on the outer circle to symbolize its role on adoption of self-regulation. Additionally, dotted lines were placed between the circles to emphasize the potential of bidirectional relationship among the EDP steps and self-regulation phases. In the present model, “ask” and “imagine” steps of the EDP was related with “forethought phase” of self-regulation while “plan” and “create” steps were correspond with “performance phase”, and “test & improve” step was align with “self-reflection phase”.

Ask step of the EDP is the initial stage that problem/need is examined based on the criteria and constrains. After ask step, imagine step is where the various design solutions are generated for the problem/need. Ask and imagine steps of the EDP was correlated with the processes of forethought phase since it is the phase in which goal of learning and specific strategies to conduct to task are determined with motivational beliefs like behavioral attribute of information interpreting of observation was correlated with forethought phase at the model of Li et al. (2020). Moreover, several studies have revealed that engineering design task enhances the task analysis and motivational beliefs of individuals (Chyung et al., 2010; Lawanto et al., 2013; Lemons et al., 2011).

Plan step is actualized with writing down the steps of best solution while create means transforming of solution into model. Plan and create steps of the EDP were related with the processes of performance phase since it is the phase consists of subprocesses such as task strategies, self-experimentation, attention focusing, etc. Subprocesses of performance phase of self-regulation model of Zimmerman (2000) are useful for making planning and creating model of engineering design. To illustrate, Tas et al. (2019) found that design-based science instruction has improved the usage of planning strategy.

Test and improve steps of the EDP show similarities with the processes of self-reflection phase. Test step of the EDP contains the evaluation of solution based on the criteria and constrains while improve step is about adjusting the solution to reach the determined qualifications setting primarily. Similarly, self-reflection phase contains the processes of self-evaluation in which task is evaluated based on the goals and self-judgement in which determination of future behavior for task is reasoned.

2.6 Summary of the Related Literature

In the present study, the role of engineering design-based instruction on STEM conceptions and adoption of self-regulation by the pre-service chemistry teachers in the context of environmental chemistry was investigated. Therefore, literature review was performed under the sections of conceptualization of STEM, STEM education, EDP of STEM education, the social cognitive theory and self-regulation, and finally the EDP of STEM education and self-regulation.

Emergence of STEM was aroused to make advancements in space technologies by the help of scientific knowledge and engineering (Bybee, 2010). Then, STEM has defined as educational term by different scholars. Hasanah (2020) defined STEM education based on the categories of discipline, instruction, field, and career while Jurdak (2016) proposed the different definitions for it based on the aspects of literacy, and curriculum. There are also studies that define STEM education as problem-solving ability in authentic contexts (Breiner et al., 2012; Burrows & Slater, 2015; Merrill, 2009; Morrison, 2006). Such definitions have uncovered the need of description of authentic content, problems, and procedures for STEM. Investigation about designation of these terms has resulted in emergence of integrated STEM education. There are different definitions for integrated STEM education (Bryan et al., 2015; Moore et al., 2014; Sanders, 2009). Between them, integrated STEM education definition of Bryan et al. (2015) emphasizes the importance of engineering practices since learning and teaching knowledge and practices of science and mathematics is conditioned to integration of engineering practices and its related technologies. This view supported by scholars who asserted that subjects of STEM disciplines can integrated via engineering since it provides an opportunity for dealing with real-world contexts (English, 2016; Honey, 2014; Hudson et al., 2014; Jung et al., 2023; Yata et al., 2020). Emphasizing the engineering in integrated STEM education has contributed to studies about the EDP. The main steps of the EDP determined by NGSS (2013) as "defining and delimiting engineering problems," "designing solutions to engineering problems," and "optimizing the design solution" (p. 2). After that, different models were asserted for the steps of the EDP regarding these main steps (Dym et al., 2005; Dym & Little, 2013; Farmer et al., 2012; Hoban & Delaney, 2012; Hynes et al., 2011; Massachusetts Department of Education, 2006; Moore et al., 2014; National Research Council, 2012; Tien et al., 2020). The EDP model of English and King (2015) became prominent due to easy-to-follow structure of the steps of the EDP. Five steps of their model have named as "problem scoping", "idea generation", "design and construct", "design evaluation", and "redesign". These steps were simplified in terms of nomenclature by Moore et al (2014) by changing the "ask", "imagine", "plan" and "create", as names for "problem scoping", "idea generation", "design & construct" respectively and "test" and "improve" for "design evaluation" and "redesign" processes.

To practice iSTEM activities that involve the EDP requires adoption of cognitive skills due to the multidimensional nature of these activities (Hwang et al., 2020). The social cognitive theory explains the delicacy of behaviors of individuals to cognition and environmental/social (Bandura, 1986). Triadic Reciprocal Determinism Model of Bandura (1978) presents the mutual interactions between personal, behavioral, and social/environmental factors. Zimmerman (2000) asserted the self-regulation framework depending upon the social cognitive theory of Bandura (1986). He defined the self-regulation as "self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals" (p.14) and describe the phases of self-regulation which are forethought, performance, and self-reflection (Zimmerman, 2000). There are processes with their sub-processes under each phase. Forethought phase contains the processes of task analysis (goal setting and strategic planning) and self-motivation beliefs (self-efficacy, outcome expectations, goal orientation, and intrinsic interest/value), performance phase includes the processes of self-control (self-instruction, imagery, task strategies, and attention focusing) and self-observation (self-recording and self-experimentation), and finally self-reflection phase consists of the processes of self-judgement (self-evaluation and causal attribution) and self-reaction (self-satisfaction /affect and adaptive-defensive). Since iterative nature of the EDP and cyclical nature of self-regulation model of Zimmerman (2000) show similarities, there are research about the relationship between the implication of engineering-based STEM education and adoption of self-regulation by individuals (Lawanto et al., 2013, 2017; Li et al., 2020; Zheng et al., 2020). Together these studies provide important insights about the role of the EDP for adopting self-regulation. Nonetheless, majority of these studies that assert the roadmap to investigate the EDP and self-regulation phases together are deprive of researching the steps of the EDP and processes of self-regulation in detail and examining the change in the adoption of self-regulation after experiencing engineering design-based instruction. Therefore, this study fills the gap in the literature by investigating the adoption of self-regulation throughout the EDP after taking the theoretical and practical STEM education.

CHAPTER 3

METHODOLOGY

In this chapter, detailed information about the methodology of the present study is explained under the sections of research question, design of the study, participants, data collection tools, procedure, data analysis, trustworthiness of the study, ethical considerations, limitations, and assumptions of the study.

3.1 Research Question

The aim of this study is to understand the role of engineering design-based instruction on the pre-service chemistry teachers' STEM conceptions and adoption of self-regulation. Therefore, the present study addresses the following research question:

"What is the role of engineering design-based instruction on the pre-service chemistry teachers' STEM conceptions and adoption of self-regulation in the context of environmental chemistry?"

3.2 Research Design

In the present study, the role of engineering design-based instruction on the pre-service chemistry teachers' STEM conceptions and adoption of self-regulation were investigated by utilizing qualitative research method. Because qualitative study has an interpretive tradition and embraces the open-endedness associated with pedagogies of freedom, Dimitriadis (2016) proposed the term "qualitative inquiry" instead of "qualitative research". On the other hand, Denzin and Lincoln (2011) have explained the "qualitative research" by underlining the need for interpretive practices of informants and empirical materials of these practices and emphasizing power of qualitative research about changing social constructions. Creswell (2013) defined the qualitative research by taking the definition of Denzin and Lincoln (2011) as a reference and expanding it by adding research process that linked up with philosophical and interpretive/theoretical lenses. The current study is designed as qualitative research based on the definition of Creswell (2013) by taking into consideration philosophical assumptions, interpretive framework, collecting data in natural setting, and the way of analyzing data.

Firstly, there are philosophical assumptions that should be pursued while performing qualitative research named as paradigm which contains axiology, epistemology, ontology, and methodology (Denzin & Lincoln, 2018). According to the definition of Creswell (2013), axiology is related to values of researcher and informants; thus interpretation of data in the present study was performed by keeping in mind value-sensitive nature of qualitative research. While my role was to understand probable knowledge of informants as epistemologically, multiple realities were espoused ontologically. Additionally, detailed description of context and revision of questions in the instruments were taken as a primitive methodology that is related to the process of research in this study.

Secondly, philosophical assumptions indicated above directed at post-positivism as an interpretive framework in qualitative research for this study. Adopting post-positivist paradigm is well suited the present study since the study was conducted by taking different perspectives and experiences of each participant into consideration for the same experience like Popper who is post-positivist claimed in the falsification theory (Sfetcu, 2019). From this perspective, to increase the probability of observing occurrence change in STEM conceptions and usage of self-regulation processes of the participants of the current study, various instruments were preferred to collect data and results were reported from the theoretical lens of scientific approach (Creswell, 2013; Corry et al., 2018).

Thirdly, data related to the implementation of engineering design process (EDP) was collected from informants in natural setting that was chemistry and science laboratory of faculty that informants were familiar with beforehand. Finally, data analysis was carried out to find the patterns like recognizing constellations in the galaxy. In other words, with the help of thematic analysis that is the milestone method for qualitative analysis in which data are dug systematically so that patterns can evolve, and themes can be formed (Braun & Clarke, 2006). Overall, the present study is well-suited to conduct by using qualitative research in accordance with overlapping the tenets defined by Creswell (2013).

Of the different qualitative research methos, this study falls into "basic qualitative research." Basic qualitative research, defined by Merriam (2009), emphasizes that participants construct the meaning of their experiences and interpret these experiences accordingly. Because the nature of the present study is centered around the understanding of how participants have constructed the meaning of STEM and adopted self-regulation, it shows the characteristics of basic qualitative research. Like in the basic qualitative research, data analysis is conducted throughout repetitious patterns found in the findings. In addition, the perspicacity the researcher about the participants' understanding of the subject is crucial in basic qualitative research. Since the researcher is knowledgeable about the context, the participants' understanding of STEM education and adoption of self-regulation has been reflected more precisely in the present study.

To sum up, basic qualitative research was employed as research design in the present study since how the pre-service chemistry teachers constructed the meaning of STEM education and interpret their experiences throughout engineering design-based instruction was investigated with respect to both their conceptions about STEM and adoption of self-regulation.

3.3 Participants

Participants of the present study was selected by using purposive sampling. Purposive samples are selected based on the non-random sampling method in which selected participants serve the aim of providing insight about the studied phenomenon (Fraenkel et al., 2012).

Since the aim of this study is understanding the role of engineering design-based instruction on the pre-service chemistry teachers' STEM conceptions and adoption of self-regulation, the participants were chosen based on the criteria with the purpose of collecting data with less possibility of error. To achieve this, four participants were selected from chemistry education program who enrolled in teaching method course since pre-requisites of this course already make participants familiar to educational methods and strategies of self-regulation respectively. Table 3.1 shows the participants' gender, GPA, and pre-knowledge about STEM.

Name*	Gender	GPA	Pre-knowledge of STEM
Deniz	Female	2.28	No
Ekin	Male	2.49	No
Ulaş	Male	2.54	No
Yağmur	Female	2.45	No

Table 3.1 Demographic Information of the Participants

* All names used are pseudonyms.

All of the participants of the study have completed general chemistry, basic physics, calculus, and learning and teaching theories courses which are important courses for developing the capability of designing the system in STEM activity and grasping the importance of STEM education.

In addition, the answers to the question “Do you have any experience about STEM?” showed that none of the participants have any experience about STEM which implies that they lacked knowledge about STEM education before taking part in this study. Furthermore, based on the pre-interview results conducted to obtain demographic information about the participants, the pre-service teachers are externally regulated, i.e., they mostly rely on external sources such as teachers and internet to plan and monitor their study, and apart from self-evaluation they barely applied the self-regulation strategies while studying. Therefore, it can be said that the pre-service teachers in the study are poorly self-regulated while studying their courses.

3.4 Data Collection Tools

In his book “*Qualitative Research and Evaluation Methods*”, Patton (2002) highlighted the importance of in-depth interviews, written documents, and direct observation as tools for obtaining rich qualitative data. In the line with perception of Patton (2002), to obtain rich information about participants’ STEM conceptions and self-regulation, data of the study were collected using multiple sources which are semi-structured interviews and think aloud protocol.

3.4.1 Semi-structured Interviews

Within the scope of the research question and the research method of the present study, pre- and post-interviews were conducted with the pre-service chemistry teachers. The pre-interview was conducted to understand the pre-service chemistry teachers’ descriptions and opinions about STEM and STEM education and to investigate their self-regulation before taking the engineering design-based instruction and practicing of the EDP throughout STEM activity. The post-interview was carried out to understand the pre-service chemistry teachers' descriptions and opinions about STEM and STEM education after they were informed about STEM and performed STEM activity.

The interview protocol was prepared considering the related literature (e.g., Moore et al., 2009; Sanders, 2009). The questions in the interview protocol particularly focused on acquiring in-depth information about the participants' current state of STEM conceptions and adoption of self-regulation in their general study habits. It was examined by an expert who is knowledgeable about STEM and self-regulation. After taking the expert's opinion, the content of the interview questions was remained unchanged whereas the format of the questions was simplified in terms of the length and tone of voice used to ask questions.

As soon as required revisions were made in the interview protocol, a pilot study was performed with two pre-service chemistry teachers. The participants of the pilot study have knowledge and practice about STEM. As a result of the pilot study the question of "What does integrated STEM (iSTEM) education mean?" was converted to "What do you know about the integration of the disciplines within STEM?" Since iSTEM is a domain specific term, prior question sounded like dichotomous question and revising the question, therefore, might be helpful to promote the participants' rationalization of iSTEM which might be helpful to better understand the current state of their knowledge. Since other questions worked well, they remained unchanged. Sample interview questions about STEM and STEM education are:

"What is your opinion about STEM education?"

"What do you know about STEM?"

The questions related to self-regulation were asked in the pre-interview. Six core questions directed to the participants were prepared depending on the Zimmerman's (2000) cyclical model of self-regulation that contains forethought, performance, and self-reflection phases. Regarding to forethought phase there were three core questions to understand how the participants get prepared to study an unknown subject like “If you were going to study STEM, what would you do before you start studying?” There was one core question corresponded to performance phase to discover the learning strategies of the participants to unknown subject like “How do you study STEM? Do you have any technique(s) you use when learning a subject that is new to you?” For the last phase of self-regulation that is self-reflection, there were two core questions to find out what participants do after learning to unknown subject like “Do you evaluate whether you learned STEM? If you think you can't learn, what do you do?”

Semi-structured interviews were conducted with each participant separately via web conferencing platforms by the researcher. The interviews were conducted after informing participants about the confidentiality of the information that they will share. The interviews were recorded with the help of video conferencing software and voice recorder. While the pre-interviews that contain questions about both STEM and self-regulation extended about an hour, post-interviews lasted about half an hour because they included only STEM questions. After the interviews were conducted, verbatim transcription has done by the researcher via speech-to-text software.

3.4.2 Think Aloud Protocol

Ericson and Simon (1980) defined think aloud protocol as a way of obtaining information about individuals’ internal states specifically their working memory by asserting verbal reports as data. Think aloud protocol is a useful instrument for expanding the vision of data in terms of identification of which and how knowledge was used by informant while dealing with unfamiliar or problematic situation (Fonteyn et al., 1993). Therefore, think aloud protocol was employed in the present study to understand adoption of self-regulation by the participants while solving a STEM problem after taking engineering design-based instruction and practicing engineering-based STEM activity.

The think aloud protocol was piloted with two pre-service chemistry teachers. The findings of the pilot study showed that the visual about industrial manufacture of paper should be changed with the simpler one since it might cause confusion as the process is so complex. Therefore, the visual has been changed before introducing the task to the the participants. Following the post-interviews, think aloud protocol was enforced for each participant individually by emphasizing the importance of verbalizing every thought. The think aloud protocol involves a STEM task about the upcycling of scrap paper. The scenario of the task was fictionalized by proposing schools as a source of producing scrap papers and giving the role of engineer to the participants for solving the upcycling problem of scrap papers by designing a system. It was expected from the participants to design multiple systems and selected the best one by considering materials, criteria, and constrains to upcycle the scrap paper. When the participants completed their system designs, four questions about the EDP that overlap with the Zimmerman's cyclical model of self-regulation (2000) were asked (see Table 3.2).

Table 3.2 Questions Asked in Think Aloud Protocol

Question Number	Questions About the EDP	Corresponding Self-regulation Phase
1	How do you start designing strainer system?	Forethought
2	How do you design strainer system to meet the criteria?	Performance
3	How do you test compliance of strainer system with the given criteria?	Performance
4	If strainer system does not meet the criteria, how do you make it comply with the criteria?	Self-reflection & Performance

The think aloud protocol of each participant was recorded via video conferencing software and voice recorder. Screen of the computer was shared with the participant to show STEM problem, materials, criteria, and constrains. The photographs of drawing and notes about the task were taken from participants. The duration of the task was approximately 40 minutes. Records were transcribed verbatim.

3.5 Data Collection Procedure

Before starting to the study, initial literature search was done to become knowledgeable about the study area and state the research question. Then, to ensure originality of the research, a detailed literature search was carried out via Educational Resources Information Center (ERIC), Web of Science (WOS), ScienceDirect, Google Scholar, YÖK National Thesis Center and METU Library Online Database by using "STEM and engineering design process," "STEM and self-regulation," "engineering design process and self-regulation," "STEM and pre-service teacher," "engineering design process and pre-service teacher," "STEM and the pre-service chemistry teacher," and "engineering design process and the pre-service chemistry teacher" as descriptors. After detailed literature search, research design was determined as basic qualitative research. Data collection instruments were determined as interview and think aloud protocol. After ethical approval of Middle East Technical University was taken (see Appendix A), pilot studies of interviews and think aloud protocol were performed. Afterwards, the pre-service chemistry teachers were informed about the study and their consent was received.

The present study was implemented in 2023-2024 fall semester. Period of time for implementation of the EDP was four weeks, approximately six hours a week. Before engaging STEM activity, the pre-interview was done with each of the participants to understand their STEM conceptions and self-regulation. After pre-interviews were completed, engineering design-based instruction was implemented.

After STEM activity was completed, post-interviews were conducted with each of the participants about their STEM conceptions. In addition, the think aloud protocol was applied to understand their self- regulation while they were engaging in STEM task.

3.6 Implementation

Before the implementation of STEM activity, the participants took the instruction about the history of STEM, definition of STEM education and iSTEM, importance of STEM education, STEM literacy, and the EDP in STEM education. After this theoretical part, to promote the pre-service teachers' understanding of STEM education, it was demanded from them to propose a problem that they encountered in daily life. They proposed the short duration of battery life in cell phones and discuss possible solutions for the problem by referring the disciplines of STEM. The instruction was performed by the researcher in the content of the teaching methods course. It took approximately four class hours and during and after the instruction, the questions of the participants were answered.

The content of STEM activity in the study was selected from the chemistry curriculum of Ministry of National Education (MoNE). The detailed information about the grade, unit, and objectives are as follows:

Grade: 9

Unit: 5-Nature and Chemistry

Objectives:

9.5.1. Water and Life

9.5.1.1. Students should be able to explain the importance of water for all living creatures.

The importance of water and water resources is explained.

9.5.1.2. Students should be able to offer suggestions for water saving and develop solutions for protection of water resources.

The importance of careful usage of water for future of their country and world as conscientious citizens is emphasized.

The reason behind the selection of “Nature and Chemistry” unit was that despite of sensitivity of students about environmental issues was recognizable, their knowledge was inadequate (Aydın & Kaya, 2011; Hager et al., 2006; Wardani et al., 2018). Becoming experienced on STEM activity that focused on developing solution of water deficiency might create an opportunity for the pre-service chemistry teachers to share this experience with their future students and then to increase their knowledge and consciousness about environmental issues.

STEM activity was generated to find a solution to excessive amount of water consumption by designing drip irrigation system. The researcher has presented STEM activity that the participants were expected to perform step by step and showed the video about drip irrigation system and visuals about permaculture areas. Beside showing the steps of the EDP via presentation, a handout of STEM activity was also distributed to the participants. STEM activity handout consisted of two main sections. The first section was about informing participants about the current state of resources of water, how drip irrigation systems are beneficial to use saving water, and detailed information about working principle of drip irrigation systems. The second section was about designing drip irrigation system. In this part STEM problem “You are team of engineers who will work in the drip irrigation system that will be designed for the permaculture area planned to be established at a University of X. Create a prototype of the system that will optimally meet the conditions” was introduced by carrying global problem of water deficiency to familiar context and materials to make their prototype with criteria and constrains that they follow were demonstrated. In this section steps of the EDP that are ask, imagine, plan, create, test, and improve were followed by the participants to design a drip irrigation system. During the implementation of STEM activity, nonparticipant observation was done by the researcher.

3.6.1 Ask

For the “ask” step of the EDP, the participants were expected to identify the problem of diminishing water consumption in agriculture by taking the permaculture area in their university as sample like “How the amount of water used up for irrigating the permaculture area in the University of X can be reduced with the help of drip irrigation system?” The participants filled the “ask” part of the handout that includes problem section by writing “lack of access to clean-drinking water globally. For University of X, lack of clean water to create permaculture area” while they left criteria and constraints sections unfilled.

3.6.2 Imagine

In this step, the participants were expected to generate multiple design solutions, discuss the advantages and disadvantages of each design solution and determine the best design of drip irrigation system for permaculture area. The participants have drawn two designs for the drip irrigation system which differs in terms of position of the filtration system (see Figure 3.1). They chose the second design system and wrote down its pros and cons.

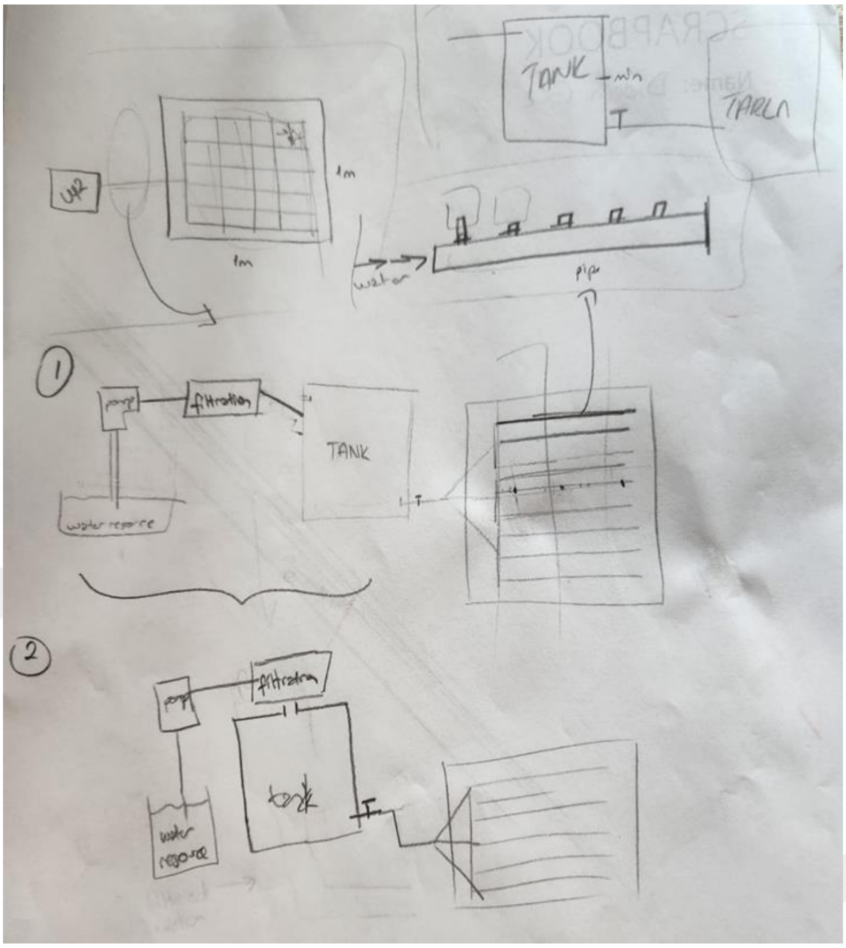
Figure 3.1 Drawings of the Possible Design Solutions

3.6.3 Plan

At the "plan" step of the EDP, the participants should provide information about how they construct the drip irrigation system by obeying the criteria and the constraints of the problem. For example, filtration system will be built using water bottle that will be filled with gravel, sawdust, and cotton with same amount from top to bottom with respect to decreasing pore sizes. It will be placed on the tank to be benefit from gravitational force in the separation technique of filtration.

The participants wrote down their plan about how to construct their prototype without giving the details about the materials such as their dimensions and the amounts (see Figure 3.2). Moreover, in this step, there were statements related to “ask” and “test” steps of the EDP as follows:

“To understand the problem” (“ask” step of the EDP)

“Check the system” (“test” step of the EDP)

Since the participants missed out the listing materials and criteria and constraints at the “ask” step, after they have seen the materials, they have changed the design that they chose at the “imagine” step by eliminating fertilizer in their system designs and putting cross on fertilizer. Additionally, they have an issue about the filling handout as it can be seen in the Figure 3.3, they write “plan” under the section of “imagine”:

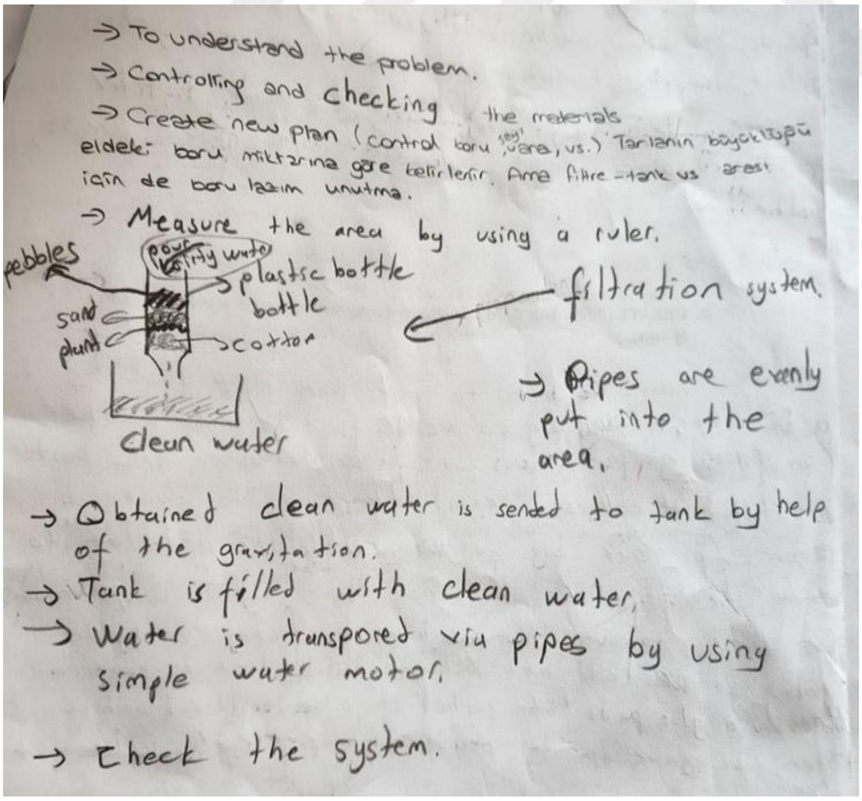

Figure 3.2 Plan of the Participants about Their Design Solution

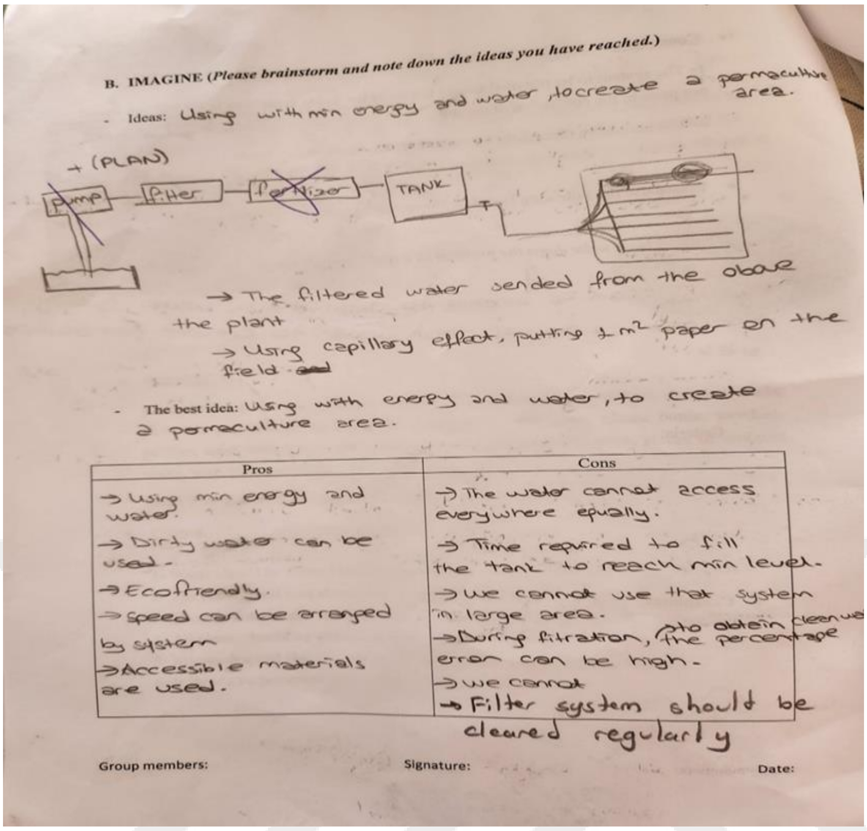

Figure 3.3 Drawing of the Participants' Design Solution

3.6.4 Create

A prototype of the drip irrigation system should be constructed at the "create" step. At this step, the participants were expected to follow the specific steps to create the prototype consciously instead of conducting random attempts.

During the construction of the prototype, the participants divided it into sections as filtration system, pump, tank, and soil field (Figure 3.4) and then put all these parts together to complete their system.

Figure 3.4 Construction of Prototype

3.6.5 Test

"Test” step of the EDP demands controlling the suitability of prototype according to the criteria and constraints and detecting the things needed to be changed in the system. Therefore, the participants should check whether their drip irrigation system works or not based on the criteria of filtration of water, number of drops per unit, the dimensions of irrigated area, and equal irrigation of plants.

After testing their system, the participants decided to remove the water pump from their design. The water pump design took water and stopped working so participants designed a coverage for pump with lids seen in the Figure 3.5. However, the system of covering pump with lids did not work, so they designed another system with a syringe to transfer the water (see Figure 3.6). The amount of the water was not sufficient into the system, so they gave up this system either. At the end, they decided to use gravity as supporting force to pull the water and so they increased the height of the filter system in which water was spilt.

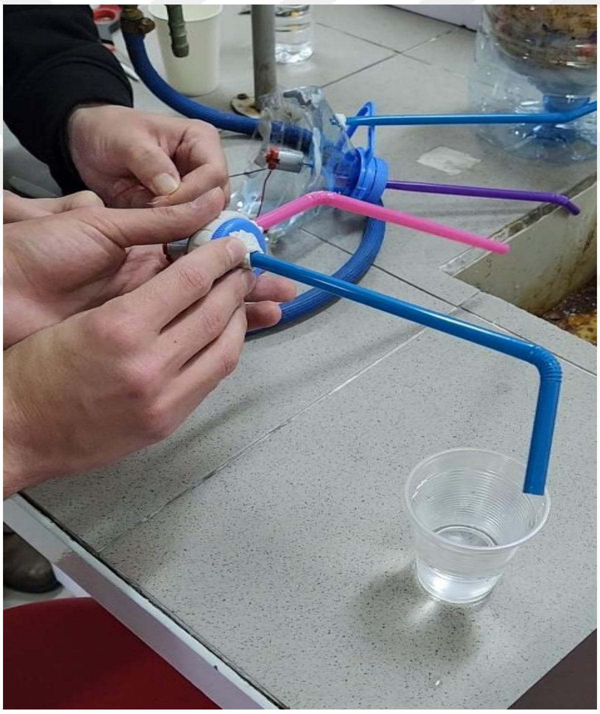

Figure 3.5 Water Pump Design

Figure 3.6 Water Pump Design with Syringe

When the participants completed their design, time was given to prepare their presentations. They explained their system to the researcher and instructor of the teaching methods course. They have taken feedbacks about explaining the scientific background about their choices, working mechanism of the system during design process, and how they have met the criterion of number of drops per minute with mathematical calculation. The prototype of their design can be seen in the Figure 3.7.

Figure 3.7 Prototype of Drip Irrigation System

3.6.6 Improve

The “Improve” reveals iterative nature of the EDP. Therefore, the participants were expected to make modifications to meet the requirements of the criteria and retest their prototype. The participants made modifications about the number of drops per minute by opening the holes on straws at certain intervals (see Figure 3.8). Then, they have presented their prototype again which met the criteria indicated at the beginning of the task which were usage of filtered water, dimensions of soil area, amount of the water that should be used to irrigate, number of drops per minute.

Figure 3.8 Modifications of the Prototype

Table 3.3 summarizes the implementation STEM activity with explanations.

Table 3.3 Summary of the Implementation of the STEM Activity

Week	Content
Week 1	Pre-service chemistry teachers were informed about STEM education and engineering design process theoretically. Group of four pre-service chemistry teachers were formed. STEM activity handout was distributed, and STEM problem was introduced. By following STEM activity handout, the pre-service chemistry teachers started engaging in the EDP in STEM. After reading the literature about STEM problem, the pre-service chemistry teachers completed the steps of the EDP that are “ask” by writing the problem as a real-life question and “imagine” by making brainstorming.
Week 2	The pre-service chemistry teachers wrote the “plan” of their best design idea and “create” their prototype of this design and “test” it.
Week 3	The pre-service chemistry teachers presented their prototype. Verbal feedback from researcher and course instructor were provided for their presentation and one week was given to think about the changes that should be made to meet the criteria and constrains.
Week 4	The pre-service chemistry teachers finalized iterative process of their design of prototype and “improved” it based on the feedbacks and redesign their prototype. Then, the pre-service chemistry teachers presented improved form of their prototype. Their presentation was evaluated by researcher and course instructor.

3.7 Data Analysis

Data analysis is described as a process of making sense of data and reaching a reasonable conclusion (Merriam, 2002). Although there is no certain formula to convert data to findings for qualitative studies, there exists a guidance to execute this transformation (Patton, 2002). According to Bogdan and Biklen (2007) data analysis procedure takes place starting with working on data and followed by organizing data, breaking them into manageable units, coding them, synthesizing them, and searching for patterns.

In the present study, content analysis was used to analyze data. Content analysis is a technique in which behaviors and knowledge of people were examined via analysis of written contents of their communications in general (Fraenkel et al., 2012). The written documents to analyze STEM conceptions and usage of self-regulation processes of the participants were obtained with verbatim transcription of audio records of pre- and post-interviews and think aloud protocol in this study. After preparing the data for the qualitative content analysis, they were read and reread several times and then analyzed by using both inductive and deductive approaches. The inductive approach was carried out by deriving codes from the data, while in the deductive approach, the data were coded by using frameworks from literature (Patton, 2002).STEM conceptions of the pre-service chemistry teachers was analyzed through inductive approach while their self-regulation during the EDP in STEM actvity was analyzed deductively by using Zimmerman’s cyclical self-regulation model (2000) and engineering design process models of Moore et al. (2014) and English and King (2015).

3.7.1 Analysis of the Interviews

For analyzing the data about STEM conceptions of the participants from pre- and post-interviews, inductive approach was utilized. The transcribed data of the interviews were analyzed and repeated statements were detected. Then, statements were compared, and the smallest meaningful units were described as code (Denzin & Lincoln, 2011). After iterative coding process done by the researcher and expert, and reaching consensus on the codes, a final coding protocol was obtained to investigate STEM conceptions of the participants.

The coding protocol describes understanding of the pre-service chemistry teachers about STEM education. All of the data obtained from the pre- and post-interviews related to STEM were coded based on the coding protocol. After the final version of the coding protocol has been determined by the researcher and expert, two themes emerged from the codes: “Description of STEM” and “ Opinion of STEM.” Under the theme of “Description of STEM”, “definition” and “nature” exist as sub-themes. “Definition” arises from the codes of “method,” “product,” “project-based,” “use of scientific knowledge,” “based on real-life,” “student-centered,” “motivation for learning,” and “EDP.” On the other hand, “nature” sub-theme is made up of the codes “level of integration,” “degree of integration,” and “representation of disciplines.” These three codes have sub-codes “disciplinary,” “multidisciplinary,” “interdisciplinary,” and “transdisciplinary” for the code of “level of integration”; “content,” “supported content,” and “context” for the code of “degree of integration” and “science,” “technology,” “engineering,” and “mathematics” for the code of “representation of disciplines.” The theme of “Opinion of STEM” arises from the sub-themes of “importance” and “limitations.” The codes under the sub-theme of “importance” are “meaningful learning,” “retention,” “workforce,” “time management,” “21st century skills,” “communication skills,” and “problem solving skills” while “tinkering” and “time consumption” are the codes of the sub-theme of “limitation”. The operational definitions of the codes were determined based on the relevant literature (Al-Rawi, 2013; Bailey & Colley, 2015; Bryan et al., 2015; Costa et al., 2022; Cullen & Guo, 2020; Custers, 2010; English & King, 2015; Ferguson, 2011; Hartman, 2016; Lederman, 1992; Lederman & Lederman, 2020; MacCann, 2012; Poce et al., 2019; Prince & Felder, 2006; Rahman, 2019; Sharma & Yarlagadda, 2018; Thitima & Sumalee, 2012; Vasquez et al., 2013, as cited in English, 2016; Yılmaz, 2009) as shown in Table 3.4.

Table 3.4 Coding Protocol for the STEM Conceptions of the Participants

Theme	Sub-theme	Code	Sub-code	Explanation	Sample excerpt
Description of STEM	Definition	Method	-	The mechanism employed by educators to organize and execute a multiple of educational resources and activities aimed at attaining specific learning objectives	"I can explain it as a method that progresses within a certain framework."
		Product	-	Artifact constructed to solve the problem	"There must be something that works at the end"
		Project-based	-	Engaging with task which promotes the creation of product such as design, model, simulation, device etc.	"It could be something technological, or it could be a scientific experiment or project like lessons are integrated into something like an output"
		Use of scientific knowledge	-	Seeking knowledge in inductive and deductive reasoning to think of an answer or identify and to explore the scientific examination of the facts	"…While doing this, developing a design using scientific knowledge and some principles based on evidence…"
		Based on real-life	-	Local or global situation that happened or possibility to happen in daily life	"… They need to question and apply it in real life, whether they have really learned it or not"

Table 3.4 (Continued)

Theme	Sub-theme	Code	Sub-code	Explanation	Sample excerpt
Description of STEM	Definition	Student-centered	-	"Bottom-up" approach in which the role of teachers is facilitator, and they encourage students to be independent learners	"There should be experiments, etc. Students should participate in the lesson by embedding the principles of science"
		Motivation for learning	-	The attribute that affects choices of the individuals to spend time and energy they give task as well as how they think and feel about it.	"To attract students' attention and make them like the subject, I think that the subject should be repeated for the best to the worst student, …, the psychology of the student should be considered more. It is related to educational psychology but integrated into the course."
		EDP	-	Process that consisting of five steps that are problem scoping, idea generation, design and construct, design evaluation and redesign	"…there is the designing part and the part of making it real…In the engineering part, the operation of the mechanism, testing, etc. are also carried out through scientific steps."

Table 3.4 (Continued)

Theme	Sub-theme	Code	Sub-code	Explanation	Sample excerpt
Description of STEM	Nature	Level of integration	Disciplinary	Approach in which each STEM discipline learned based on silo approach scenarios	"I think they are all covered separately, but I don't know how they are related to each other"
			Multidisciplinary	Approach in which learning of STEM disciplines happens separately but there is a common theme while learning of disciplines	"A true inference can be made by combining history and geography…"What has been seen in history?". Settlement in certain areas, etc. "What is the reason for this?" It's actually geography…"

Table 3.4 (Continued)

Theme	Sub-theme	Code	Sub-code	Explanation	Sample excerpt
Description of STEM	Nature	Level of integration	Interdisciplinary	Approach in which similar concepts and skills from two or more STEM disciplines to go beyond the comprehension of these disciplines	"Because when these four come together, they form a whole. Therefore, if even one of them is missing, the problem cannot be solved better. So, it can be solved much better using all four"
			Transdisciplinary	Approach in which integration demands the application of knowledge of STEM disciplines to real-world scenarios	"To develop a project that eliminates the problems we will encounter in our daily lives. While doing this, using scientific knowledge, developing a design based on evidence, using some principles, and being able to design it like an engineer, making calculations, that is, making a design that will work properly…"

Table 3.4 (Continued)

Theme	Sub-theme	Code	Sub-code	Explanation	Sample excerpt
Description of STEM	Nature	Degree of integration	Content	Integration of units or practices that has various learning goals from different disciplines exists	"The best thing is to use them all together. It would be perfect to use all of them, but using two is actually enough"
			Supported content	Covering one subject of discipline with the help of learning goals of other subject of discipline	"It can be seen that some branches dominant at certain times. There is no intention here to make them all equal… "
			Context	Attaining the goal of the discipline by using other discipline as context	Not existent

Table 3.4 (Continued)

Theme	Sub-theme	Code	Sub-code	Explanation	Sample excerpt
Description of STEM	Nature	Representation of disciplines	Technology	Both the tools and the systematic processes that is used to solve problems	"…and that is mostly in the field of computers, things like software and hardware"
			Engineering	Body of knowledge, set of practices, and way of knowing (demarcation, EDP, empirical basis, tentativeness, creativity, subjectivity, cultural embeddedness, failure-laden, criteria and constraints)	"For example, making a wheel or installing elevator system. I can think a system that works with specific purpose"
			Mathematics	Numbers or a set of rules while mathematicians define it as study of patterns	"It is a tool for calculation. Mathematics is a measuring tool, numbers tell the truth. By looking at the numbers, we create a logic and calculation in our minds…"

Table 3.4 (Continued)

Theme	Sub-theme	Code	Sub-code	Explanation	Sample excerpt
Opinion of STEM	Importance	Meaningful learning	-	Active and constructive learning that taking place when learners develop knowledge in response to their environment, reflecting on activity and articulating what they have learned	"…when I don't integrate them, I think of them all as separate. Since I think of them all separately, I don't have a map in my mind and after a while, I start memorizing them ..."
		Retention	-	Proportion of knowledge gain to knowledge loss	"When we think of STEM, student knows how to apply and solve problems... In fact, he immediately starts to remember how it was solved and starts to take action thanks to STEM"
		Workforce	-	People who are innovative, creative, possessing critical thinking and problem-solving attitude and keep up with new technologies	"…Thanks to STEM, we raise individuals who will learn the formula and add to it, rather than individuals who will use the formula"

Table 3.4 (Continued)

Theme	Sub-theme	Code	Sub-code	Explanation	Sample excerpt
Opinion of STEM	Importance	Time management	-	Set of habits that can be improved with training or deliberate practice by using strategies like organization and planning	"For example, students will be able to learn how to manage time, this lesson will be useful in the future. I think they gain a little practice for university or for their work lives"
		21st century skills	-	Refined description of skill as 4C: critical thinking, communication, collaboration, and creativity	"… we need to integrate this both in our thoughts and in our daily lives, and in our schools and students, technology is already integrated in these areas…I think it is a necessity of the age."

Table 3.4 (Continued)

Theme	Sub-theme	Code	Sub-code	Explanation	Sample excerpt
Opinion of STEM	Importance	Communication skills	-	Process of face-to-face communication between at least two people which is beneficial in terms of influencing each other and solving conflicts	"…STEM should definitely be included in education is to increase students' discussion skills and encourage them to explain themselves… There is already cooperation, we can communicate. We can express our opinions, listen to and criticize others' ideas…STEM projects will definitely be better for students to explain themselves and express the ideas they advocate ."
		Problem solving skills	-	Cognitive process that is related with reaching a goal for which the students do not know a solution at first	…When they encounter such a [problematic] situation, they say, "Okay, I can do something like this." For example, welding a plastic bottle with a silicone gun…Great for problem solving skills."

Table 3.4 (Continued)

Theme	Sub-theme	Code	Sub-code	Explanation	Sample excerpt
Opinion of STEM	Limitation	Tinkering	-	Making of an activity, not a mindset	"…It was not a phase of trying to learn, but a phase of producing something for us, and it will be the same for the student."
		Time consumption	-	The activity or process requires time span that exceeds the duration of lesson indicated in curriculum	"We spent a lot of time, when performed again, it might be reduced by a few hours, but we would still spend a lot of time…I definitely see it as something that requires time. It certainly cannot be reduced to limited time"

3.7.2 Analysis of Think Aloud Protocol

The think aloud protocol was conducted to understand the pre-service chemistry teachers' STEM conceptions and adoption of self-regulation processes while finding solution to STEM problem by following the steps of the EDP. Therefore, similar to the pre- and post-interviews, the audio records of the think aloud protocols transcribed verbatim and read several times by the researcher. Then, the transcribed data were analyzed by using deductive approach (Patton, 2002). After all the data were coded by the researcher and two of the think aloud protocols by the researcher and expert, the themes were determined as "EDP" and "self-regulation." The coding protocols were finalized after consensus. The coding protocol for the implementation of the EDP was employed by using the models of Moore et al. (2014) and English and King (2015). The coding protocol for analyzing the steps of the EDP in the study is depicted in Table 3.5. In their studies Tank et al. (2018) claimed that usage of direct terms for the steps of the EDP makes the process more understandable for practitioners. Moore et al. (2014) had simplified the nomenclature of engineering design process by using the "ask," "imagine," "plan," and "create," as the titles for "problem scoping," "idea generation," and "design & construct" respectively and "test" and "improve" for "design evaluation" and "redesign" processes. Although the titles of the steps of the EDP are different, the descriptions of the model of Moore et al. (2014) and model of English and King (2015) are almost similar (Ali & Tse, 2023). Therefore, in the present study, the combination of both models was employed to make the coding protocol of the think aloud process more understandable and cohesive by using the steps of the "ask," "imagine," "plan," "create" and "test & improve" as the codes .

Table 3.5 The Coding Protocol for the Participants' Engagement in the EDP in Think Aloud Process

Codes of the EDP	Explanation	Sample Excerpt
Ask	Defining the design problem by considering criteria & constraints and conceptualize its function. Dividing design problem into low-order problems.	"What exactly is meant here now? It's very slim. It is produced by recycling, that is, it is produced with recycled materials. A filter system, what kind of system is this filter system now?...What do you mean by filter system?...Will the quality decrease?"
Imagine	Producing different ideas for solution of design problem to meet the criteria & constraints. Determining the best idea for solution of design problem	"I am drawing the possibilities of that frame of wire and tulle…I will try this with three different frames. First, I drew one of each frame, wire and tulle, but there are two of themI put them on top of each other. For example, I put the wire on the frame and the tulle on top of the wire. There are two layers, but I stretch them all."
Plan	Explaining the solution path of design problem step by step	"…After crushing the worn papers into small pieces, using minimum water. I'm going to glue it together and it fits all the criteria…"
Create	Constructing of prototype of best design solution	Not applicable
Test & Improve	Testing of prototype to check whether meet the criteria and constraints or not. Indicate limitations if exist and make adjustment for meeting the meet the criteria & constraints. Continue to process until meeting the criteria & constraints.	"When we add the mixture, we first test how thick it is when we add the amount of mixture…We try to do it here by adjusting it ourselves, that is, by trial and error."

The coding for self-regulation was conducted by utilizing Zimmerman's self-regulation model (2000). For analyzing the participants' adoption of self-regulation processes during the EDP, Zimmerman's self-regulation model (2000) was utilized. The coding protocol for self-regulation is presented in the Table 3.6.

Table 3.6 The Phases, Associated Processes and Sub-Processes of Self-regulation, and Sample Excerpts Used for The Analyses of Think Aloud Protocol

Phase	**Process**	**Sub-Process**	**Explanation**	**Sample Excerpt**
Forethought	Task Analysis	Goal setting	Indicating the aim of STEM task by considering the criteria and constrains	"First of all, I thought about the starting and ending points. At the beginning I have wastepaper and at the end I need to have recycled paper. It is reusable"
		Strategical planning	Deciding the methods and the materials used to reach the solution of STEM task	"First of all, I probably need to turn the papers into mud by wetting them with water. Then, probably with the help of a hammer. No, if I use enough water, the wire strainer is okay."
	Self-motivation Beliefs	Self-efficacy	Personal beliefs about having the potential to learn.	Not existent
		Outcome expectations	Beliefs about the results of performance.	Not existent
		Intrinsic interest/value	Belief about acquiring the required skills of the discipline/subject.	Not existent
		Goal orientation	Valuing the process of learning the subject due to its merits.	Not existent

Table 3.6 (Continued)

Phase	Process	Sub-process	Explanation	Sample Excerpt
Performance	Self-control	Self-instruction	Asking questions themselves about the process while developing solution to STEM task	"Do we have anything else to unify? As an adhesive, you can think of it as a mixture of ... adhesive?"
		Imagery	Forming of mental pictures	Not existent
		Attention focusing	Explaining the usage of specific material for the solution of STEM task	"Since the mosquito net has harder form, I preferred it for long-term usability…I found the mosquito net more suitable in terms of applicability."
		Task strategies	Division of STEM task into parts	"…I cut the torn paper into very small pieces…I pass it through mosquito net. All the cut papers and much smaller papers pile up below. I glue these accumulated small papers with glue. I also use water. I glue it and it creates a very uneven paper. I smooth it out by hitting it with a hammer and thin it out. Then I cut it to the desired size with scissors and a ruler…"

Table 3.6 (Continued)

Phase	**Process**	**Sub-process**	**Explanation**	**Sample Excerpt**
Performance	Self-observation	Self-recording	Control in what extent meet the criteria of STEM task	“Equal, what we've already done is to have consistent thickness. Okay, it also needs to be thin. There should be no holes in the paper.”
		Self-experimentation	Suggesting alternatives for the system to increase the opportunity of obtaining the desired results.	“Actually, I will try this with three different frames. First the frame wire and tulle. I drew one of each, but actually there are two of them and I put them on top of each other. For example, I put the wire on the frame first and the tulle on top of the wire, there are two layers, but I stretch them all…”

Table 3.6 (Continued)

Phase	Process	Sub-process	Explanation	Sample Excerpt
Self-Reflection	Self-judgement	Self-evaluation	Comparison of task performance with the criteria and constrains of STEM task.	“Since I'm using a mold of a certain proportion, it will be the same size and consistent thickness. Because it will be the same.”
		Causal attribution	Stating reason behind the result of the task	Not existent
	Self-reaction	Self-satisfaction/affect	Satisfaction or dissatisfaction about task performance	Not existent
		Adaptive/defensive	Indication of what position is taken when the comparison of performance with criteria and constrains of STEM task.	“Then I'll upgrade this pattern a little bit.”

Since the participants' adoption of self-regulation processes was investigated while dealing with STEM problem by following the EDP, the explanation of the sub-processes was customized according to STEM task given in think aloud protocol. The sub-processes of forethought phase that are goal setting and strategical planning was adapted to STEM task as "indicating the aim of STEM task by considering the criteria and constrains" and "deciding the methods and the materials used to reach the solution of STEM task" respectively. At the performance phase, self-instruction is defined as "asking questions themselves about the process while developing solution to STEM task", attention focusing as "explaining the usage of specific material for the solution of STEM task" and task strategies as "division of STEM task into parts" for the self-control process. Moreover, self-recording is described as "control in what extent meet the criteria of STEM task" and self-experimentation as "suggesting alternatives for the system to increase the opportunity of obtaining the desired results" for the self-observation process of performance phase. Self-reflection sub-processes of self-evaluation is adapted to STEM task by stating as "comparison of task performance with the criteria and constrains of STEM task" and adaptive/defensive as "indication of what position is taken when the comparison of performance with criteria and constrains of STEM task" for the self-judgement and self-reaction processes. Additionally, although the codes for self-motivation beliefs are included in the coding protocol of self-regulation due to the use of deductive coding in the study, they did not appear during data analysis, therefore these are represented as "not existed."

3.8 Trustworthiness of the Study

There are different definitions and procedures to ensure the validation of qualitative research (Creswell, 2013). Naturalistic inquiry perspective of Lincoln and Guba (1985) was adopted to describe the validation of results of presented study.

According to Lincoln and Guba (1985), answering the questions evolved from the four major elements which are truth value, applicability, consistency, and neutrality are the premises of construction of validation of research. Based on the answers to these questions, “trustworthiness” of research is defined as the ways of ensuring the readers of the study to noteworthiness of the results.

From the naturalistic inquiry perspective of Lincoln and Guba (1985), building up of trustworthiness for qualitative research requires credibility, transferability, dependability, and confirmability.

3.8.1 Credibility

Based on the framework of Lincoln and Guba (1985), credibility is defined as reliance of truth, interpretation, and representation of the data (Polit & Beck, 2012). In other words, credibility is based on the consistency between the aim of the research and methodologies applied to reach this aim (Patton, 2002). In the present study, prolong engagement, triangulation, peer debriefing, and member checking were used to maintain credibility.

Prolonged engagement is defined as spending adequate time setting of activity and/or the participants of the study (Lincoln & Guba, 1985). Streubert and Carpenter (2011) pointed out the importance of prolonged engagement to procure accurate information by emphasizing its effect on revealing the covert ideas and feelings of participants as a result of establishing relationship based on mutual respect and trust between researcher and participants. In the present study, sufficient amount of time was spent with the participants. One month period of the implementation of STEM activity helped to create an atmosphere of mutual trust between the researcher and participants and hereby their thoughts and point of views about STEM education and EDP were elicited companionably.

Besides, triangulation was used to increase the credibility of presented study. Triangulation is a way of conformation of findings by using independent measures as corroborating evidence (Miles & Huberman, 1994). There are different modes of triangulation which are usage of multiple and different sources of data, multiple theories, multiple methods, and multiple investigators for conformation of findings (Denzin, 1978, as cited in Lincoln and Guba, 1985, p.305). In the present study, data triangulation was conducting by using different types of data collection tools such as interview schedules and think aloud protocol. Together with data triangulation, investigator triangulation was practiced. Investigator (or analyst) triangulation requires analyzing the same data by different field of experts independently and then comparing their results to prevent any bias raised due to the collection of data by single person and evaluate the consistency of collected data (Patton, 2002). In the current study, transcribed interviews and think aloud protocol were coded by researcher and expert depending on the coding protocol of STEM education that was prepared by researcher and the cyclical model of self-regulation (Zimmerman, 2000).

In addition to prolonged engagement and triangulation, peer debriefing was practiced for maintaining the credibility in the study. Peer debriefing is defined as asking the criticisms of the person (a peer debriefer) who is knowledgeable about the research topic and qualified in qualitative research methods about the design of the study and collection, analysis and reporting of data to go beyond the data analysis of researcher (Creswell, 2009). In the present study, peer debriefing was maintained by taking the review of the expert about the contents related to self-regulation and STEM education, and two researchers from environmental engineering department of different universities, about the implementation and analysis of the EDP in STEM activity.

Lastly, member checking was carried out to enhance the credibility of the study. There are multiple ways for practicing member checking which are summarizing the collected data at the end of the data collection process and sharing results in written format for each participant or sharing results by meeting with group of participants after analyzing the data (Erlandson et al.,1993, as cited in Baskale, 2016). In the present study, member checking was done during the interview process after asking all questions by summarizing what was understood from the participants' explanations about questions and demanding from them to check accuracy of correctness of attributed meaning of their explanations.

3.8.2 Transferability

Transferability is described as generalization of results of the study to other contexts and group of participants (Merriam, 2009). Transferability is contingent on rich and thick description of study (Lincoln & Guba, 1985). Therefore, it is important to describe the sampling process, characteristics of participants, research process and context of the study in detail so that readers of the study can conduct similar studies. In the present study, transferability was achieved by indicating logic behind the selection of participants, giving detailed information about the characteristics of the participants, and exemplifying the questions from interview schedules and think aloud protocol with quotations from the participant answers.

3.8.3 Dependability

Analogous with quantitative research in which reliability is prerequisite for validity, credibility is prerequisite for dependability in qualitative research (Lincoln & Guba, 1985). Dependability refers to consistency and traceability of research design (Guba, 1981). Since stability of data is important to meet the criterion of dependability, application of overlaps method (kind of method triangulation) and stepwise replication (similar to split-half reliability) was suggested by Guba (1981). In the present study, stepwise replication was utilized to maintain dependability. Stepwise replication requires the separating research team and data sources into two and it was practiced in the present study separating data sources between the researcher and expert of the field. After that, consistency between the data analysis were evaluated via interrater coding and discrepancies between the coders were resolved by reaching mutual agreement.

3.8.4 Confirmability

Guba and Lincoln (1985) propound that confirmability can be achieved as long as credibility, transferability, and dependability are maintained for the study. Confirmability is described as findings and interpretations of the results of the study based on the collected data, in other words they are not figments of researcher (Tobin & Begley, 2004). Based on this definition, the need of demonstrating how findings were obtained and interpretations were made evolved. In the present study, confirmability was provided by explaining the reasons of the choice of methodology and analysis based on the theoretical framework of qualitative research. In other words, audit trail was established to verify every decision about the study from theoretical lens to data collection instruments based on rationale obtained from related literature (Koch, 1994, as cited in Nowell et al., 2017).

3.9 The Role of the Researcher

The role of the researcher in qualitative studies is expressed based on the tenets of participantness, revealedness, intensiveness, and extensiveness (Patton, 2002). Participantness is related to the role of researcher in terms of engagement of the activity/process being studied. It ranges from being full participant to complete observer. In the present study, I was a complete observer as a role of researcher since STEM activity was performed by the pre-service chemistry teachers without giving any guidance or instructional advice to them. I just observed them and took notes for myself.

Revealedness means participants' awareness about the study. It has a spectrum from full disclosure to complete secrecy. In terms of revealedness, the participants were aware of performing STEM activity since it was presented in the syllabus of teaching method course at the beginning of the semester. In addition, they gained information about the details of the study by reading the consent form distributed at the beginning of the study.

Intensiveness and extensiveness stand for expressing the time span that researcher put on the context. As an observer, I spent four weeks approximately 20 hours of time while participants designing their drip irrigation system. Additionally, I met the participants two times to conduct the pre-interview before STEM activity and post-interview and think aloud protocol after STEM activity. Therefore, I got time for building trust with the participants.

In addition to these, the researcher in the present study has a position that all of the participants were treated equally. Coding the data from the interviews and think aloud protocol objectively by obeying the operational definitions in the coding protocols also demonstrated the impartial position of the researcher.

Throughout the implication of STEM activity, the researcher was complete observer. However, since the interpretations of the researcher about STEM practices of the participants has potential to deepen the qualitative research, the participants' actions during the EDP were noted by the researcher. Asking for the description of what the participants did while performing the steps of engineering design contributed to more precise interpretations and maintained the neutral position of the researcher.

3.10 Ethical Considerations

Qualitative research is prone to ethical violations not only data collection process but also before the implementation of study, during data analysis and reporting the results of the study (Creswell, 2013). Therefore, permission of Human Subjects Ethics Committee was taken before conducting the study (see Appendix A). Information was given about the aim of the study and consent form was shared with participants. The consent form stated that there was not any mental and or physical risk of study and taking part in the study was voluntary.

Throughout the data collection process, confidentiality was assured by keeping the name of the participant anonymous, videotaping only their hands during STEM activity and putting the limit of sharing all kind of data except for the supervisor. Additionally, before starting to videotape, their permission was taken, and they were informed about being free from not responding any question and resigning before interviewing.

While analyzing the data, the importance of multiple realities kept in mind, thus, the data were analyzed without tendency toward desired results. Finally, the results were reported by referencing of related studies and avoiding any declaration that might give damage to the participants.

3.11 Assumptions and Limitations of the Study

The limitations of the present study were as follow:

1. The readiness of participants to practice STEM was not measured.
2. The materials used in STEM activity were limited to basic materials utilizing handcraft.

The assumptions of the present study were as follow:

1. Since purposive sampling was used for selection of participants, they were regarded as information-rich cases.
2. Participants answered questions of interviews and think aloud protocol independently.

CHAPTER 4

RESULTS

This chapter consists of the results of qualitative analyses of four pre-service chemistry teachers' interviews and think aloud protocols to contribute the investigation of the role of the engineering design-based instruction on the STEM conceptions and adoption of self-regulation processes of the pre-service chemistry teachers.

There are two main sections which are the results related with the STEM conceptions and the results related with the processes of self-regulation. The findings related with the STEM conceptions are presented under the themes of "Description of STEM" and "Opinion of STEM" for the results of pre-and post-interviews while the findings of the think aloud protocol are introduced under the themes of "Self-regulation" and "Engineering Design Process". The summary of findings about the STEM conceptions and self-regulation processes that were obtained from interviews and think aloud protocol are presented at the end of the related sections.

4.1 The Change in the Pre-Service Chemistry Teachers' STEM Conceptions

Participants of the study were engaged in the two interviews in a way that before and after taking part the engineering design-based instruction. Themes and sub-themes that are obtained inductively from the interviews are shown in the Figure 4.1 and Figure 4.2:

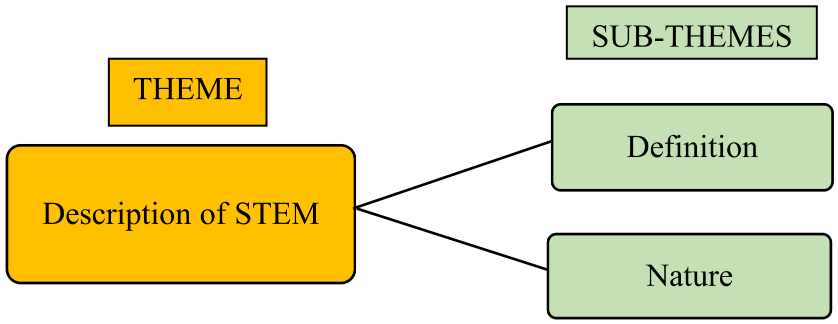

Figure 4.1 The Coding Protocol for STEM Conceptions of The Participants

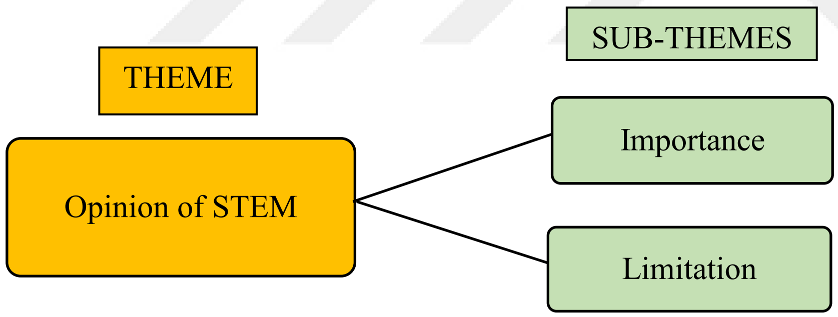

Figure 4.2 The Coding Protocol for The Participants' Opinions of STEM

The analysis of data about the "STEM Conceptions" were organized based on the participants' definitions of STEM and integrated STEM (iSTEM) while data about the nature of iSTEM as level of integration, degree of integration, and the representation of disciplines. On the other hand, participants' statements about the importance of STEM and its weaknesses were presented under the "Opinion of STEM" theme (see Appendix E).

4.1.1 The Change in the Pre-Service Chemistry Teachers' Description of STEM

Participants' descriptions of STEM were analyzed under the sub-themes of definition and nature. "Definition" was emerged as a sub-theme from the codes of "method," "student-centered," "product," "use of scientific knowledge," "project-based," "based on real-life," "motivation for learning," and "EDP. While "Nature" as a sub-theme was built on the degree and level of integration STEM disciplines as well as the representation of each discipline in STEM. Degree of integration is covered as content, supported content and context integration while level of integration is coded disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary.

4.1.1.1 The Change in the Pre-Service Chemistry Teachers' Definition of STEM and Integrated STEM

A variety way of defining STEM were expressed by four pre-service chemistry teachers before and after engineering-design based instruction. In their first interviews, the participants of the study stated the meaning of STEM by making inferences about what the letters in the word of STEM were stand for. The majority of the participants have spotted "S" for "science" while one participant has referenced it as a "student." Similarly, "technology" and "mathematics" was distinguished by most of the participants in the STEM abbreviation. On the other hand, “E” was associated with “education.” Comparing the results of the pre- and post-interviews about the abbreviation, it can be seen that all of the participants have agreed upon “S” for “science”, “T” for “technology”, “E” for “engineering” and “M” for “mathematics” in STEM acronym after engineering design-based instruction.

Beyond its abbreviation, to understand the how participants conceptualize STEM, their responses to the question: “What is STEM?” were investigated. Although range of responses was elicited, the majority of those who responded to this question tended to define by positioning it as a method for teaching at the pre-interview. In their post-interviews, however, the participants defined the STEM based on the real-life problems and focusing on the obtaining products at the end of the STEM activity. Figure 4.3 displays change in the STEM definitions of the participants after engineering design-based instruction.

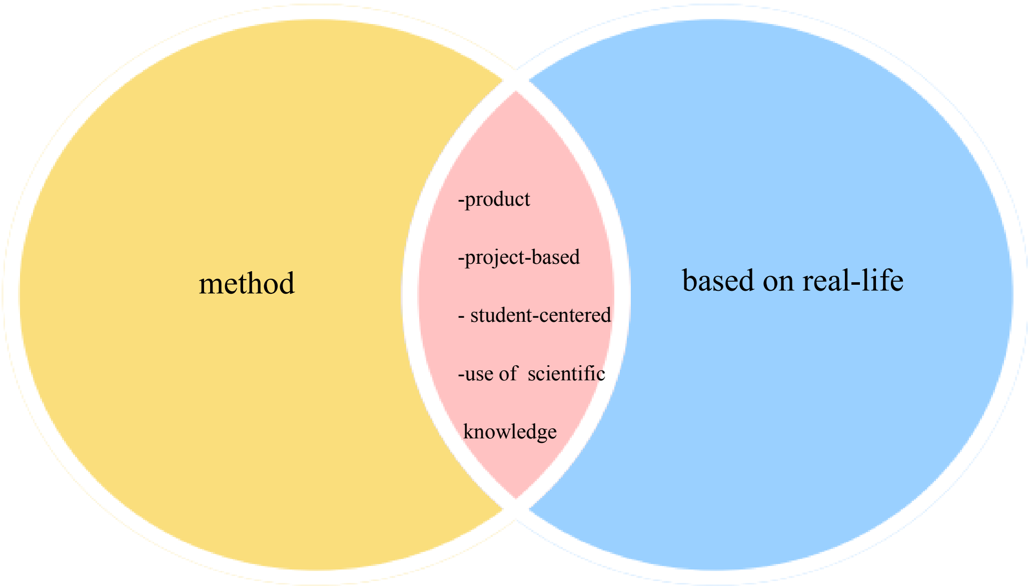

Figure 4.3 STEM Definitions of the Participants Before and After Engineering Design-Based Instruction

Note. The yellow color in this model represents the terms used by the participants to define STEM before the engineering design-based instruction, pink color represents the common terms used by the participants to define STEM before and after the engineering design-based instruction, and blue color represents the terms used by the participants to define STEM after the engineering design-based instruction.

There were two participants who defined STEM as a "method." One of them (Yağmur) indicated that "I can explain it as a method that progresses within a certain framework. There is a framework. For example, you first show it, and I thought it would be presented in a combined framework of science, technology, and education."

Two of the participants underlined the "student-centered" in their STEM definitions. They expressed that:

"It's a method, but it might be a little more about students. I think STEM focuses on students. There are a lot of subjects in chemistry, and I think they cannot be taught by lecturing, that is, there should be experiments, etc. Students should participate in the lesson by embedding the principles of science." (Deniz)

"We can say that both in terms of the context of the lecture and the creation of new things sound like STEM is more student-centered " (Ulaş)

Moreover, there were opinions that paid attention to "use of scientific knowledge" as one of the basics of defining STEM. Two of the participants have explained it with the following quotes:

"…I think they cannot be taught by lecturing, that is, there should be experiments, etc. Students should participate in the lesson by embedding the principles of science." (Deniz)

"Students observe many things in daily life, but they do not know the reason behind these observations. However, they understand that science is not only about the lectures in schools, is used to explain their observations in daily life…"(Ulaş)

In addition to these, Yağmur characterized STEM as a form of making project by indicating "It is project making, making a project by using science, chemistry, and mathematics."

In addition, Yağmur stressed the formation of tangible product and stated it in her definition of STEM:

"….It could be something technological, or it could be a scientific experiment or project like a project where lessons are integrated into something to obtain an output."

To conclude, the pre-service chemistry teachers defined STEM mainly as a student-centered method before engineering design-based instruction. Table 4.1 summarizes what each of the participants emphasized in the definition of STEM.

Table 4.1 Summary of STEM Definitions of the Participants Before Engineering Design-Based Instruction

	Student-centered	Method	Project-based	Product	Use of scientific knowledge
Deniz	x	x			
Ekin					
Ulaş	x				x
Yağmur		x	x	x	

The most striking result emerging from the post-interviews was "based on real-life problem" emphasis on STEM definition. Three of the participants built their definitions on the context of real-life scenarios. The following quotes indicating how they explained STEM "based on real-life problem:"

"To develop a project that eliminates the problems that we encounter in our daily lives… it is something that people have difficulty with, and it may cause problems for them…For example, there was a lack of water in the system we built. This is an example for problem in STEM." (Deniz)

“…A system based on solving problem by using all these four disciplines to solve that problem…In fact, it can be any problem, all problems from daily life.” (Ekin)

“…Mathematics, physics, chemistry. However, [students] don't know how to use them when they encounter a problem in real life. STEM sets solving this problem as its goal. In other words, the student actually aims to overcome problems when a problem arises in real life on the basis of engineering, mathematics, from a technology perspective, from a science perspective.” (Ulaş)

Beside the “based on real-life problem,” “project-based,” “product,” “student-centered,” and “use of scientific knowledge” were recurred throughout the dataset. Three of the participants favored the “product” as one of their tenets while defining STEM. The following statements explain how they placed “product” in their definition: “This was actually like turning theory into reality.” (Ulaş) “It is a way of producing or learning something by thinking and using many fields, not a single field.” (Yağmur)

Deniz and Ekin advocated that definition of STEM should contain statement of “student-centered.” The quotes of “Student-centered, since we can raise students who curious and eager to explore by applying STEM …”(Deniz), and “It would actually be better for the students, it would be more fun, the student would be more active.” (Ekin) exemplified statement of “student-centered” in STEM definition.

Interestingly, the “project-based” and “use of scientific knowledge” were preferred while defining STEM like as it was but by different participant. Deniz stated that “…develop a project…because they [students] are addressing a problem and perceive the goal of the project as eliminating or reducing this problem.” which indicates the “project-based” and “We can use scientific knowledge and we are able to explain the design based on scientific principles…While doing [STEM] activity, developing a model by using scientific knowledge and some principles as an evidence…” which indicates “use of scientific knowledge.”

To conclude, after they took engineering design-based instruction, the pre-service chemistry teachers defined STEM as a student-centered approach that should be based on real-life problem and has a goal about the attainment of tangible product at the end of it. Table 4.2 shows emphasized aspects of the STEM definition by each participant.

Table 4.2 Summary of STEM Definitions of the Participants After Engineering Design-Based Instruction

	Based on real-life problem	Student-centered	Project-based	Product	Use of scientific knowledge
Deniz	x	x	x	x	x
Ekin	x	x			
Ulaş	x			x	
Yağmur				x	

How participants define integrated STEM (iSTEM) was also investigated to understand the role of the engineering design-based instruction on the pre-service chemistry teachers' STEM conceptions. Motivation for learning and engineering design process (EDP) were emerged as codes after the data were analyzed for their iSTEM definitions. None of the participants defined the iSTEM by pointing the aspects like real world problem, engineering practices, linking of disciplines and attainment of learning goals before they have experienced the engineering design-based instruction. Yet, participants' definitions about iSTEM have shown differences in terms of highlighting the aspects of the EDP by emphasizing the finding solutions for real-life problems through it.

Before the engineering design-based instruction one participant has responded to the question: “What is integrated STEM?” by proposing the definition for iSTEM based on the motivation of students to learn. The participant explained the iSTEM as integration of student psychology in the learning process. The sample statement is provided below:

“In order to attract students’ attention and make them like the subject, I think that the subject should be repeated in a way of everyone can understand, from the best to the worst student, …, that is, the psychology of the student should be considered more. It is related to educational psychology but integrated into the course.” (Deniz)

Engineering design-based instruction has changed the iSTEM definitions of the participants. Three of the four participants defined iSTEM based on the EDP. Two of these three participants also highlighted the importance of dealing with real-life problem for performing iSTEM. For instance, Ulaş stated:

“Teachers teach students everything, mathematics, physics, chemistry but students don't know how to use them when they encounter a problem in real life. In other words, students cannot use them effectively. STEM sets practicing of these disciplines in real life as its goal. The students aim to overcome problems on an engineering basis by using mathematical subjects, from a technology and science perspective when they encounter a problem in real life.”

When it was asked to explain the meaning of “engineering basis,” he defined the EDP by taking into consideration obtaining product by following certain steps:

“There are certain criteria required from you in engineering. Therefore, there are requirements you need to fulfill for obtaining product. We can name them as responsibilities or obligations. To obtain product, you try to reach the best result you can by using different branches of science, by trying different methods and making mistakes.”

Another participant, Ekin, who emphasized the finding solutions the real-life problem by stating the opinion as follow: "When a problem evolved, there is something that students cannot solve or understand, they want to try something new. They find something original while dealing with new thing … Actually, a system based on solving a problem."

Moreover, the most striking data to emerge from the interviews was that one participant used the nature of science (NOS) as well as the EDP while defining iSTEM. This participant expressed the iSTEM as follow:

"…there is the designing part that is the part of making solution real. There is a design part…In the engineering part, the operation of the mechanism, testing, etc. are also carried out through scientific steps. Therefore, there is also a nature of science practice here." (Deniz)

Collectively, these results indicate that taking engineering design-based instruction and experiencing the STEM activity based on the EDP improve iSTEM definitions of the participants not only using engineering as context for learning other disciplines but also the importance of real-life problems as the object of the exercise of iSTEM.

4.1.1.2 The Change in the Pre-Service Chemistry Teachers' Nature of STEM

The data obtained from the pre- and post-interviews were coded based on the level of integration, degree of integration and representation of science, technology, engineering, and mathematics in STEM.

Comparing the data of pre- and post-interviews, it can be seen that instead of disciplinary and multidisciplinary level of integration, most of the participants were pointed out interdisciplinary level of integration between STEM disciplines in the post-interviews (see Figure 4.4).

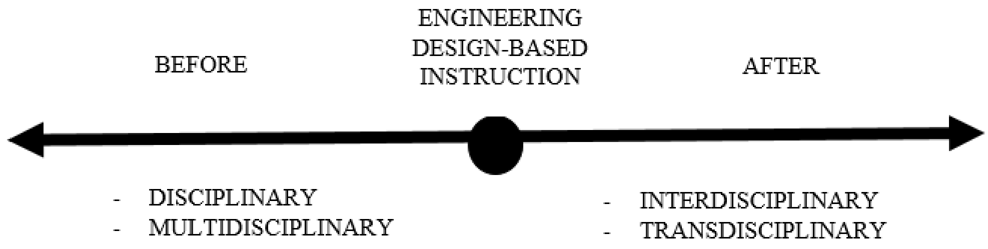

Figure 4.4 Level of Integration STEM Disciplines Before and After Engineering Design-Based Instruction

Before having engineering design-based instruction, two of the participants explained the level of integration at multidisciplinary level and one participant disciplinary level while other participant could not make explanation about the level of integration of disciplines. When the data were examined, it appeared that level of integration of disciplines in STEM did not advance the levels of interdisciplinary and transdisciplinary. For example, Ekin explained the integration at disciplinary level by stating: “I think they are all covered separately, but I don't know how they are related to each other.” Other two participants approached the integration level of disciplines by emphasizing the independent practice of learning of disciplines in a common theme. The excerpts for multidisciplinary level are as follow:

“A true inference can be made by combining history and geography. You know, in high school for example, “What has been seen in history?” Settlement in certain areas, etc. “What is the reason for this?” It's actually geography. In other words, these two are combined and explained to the student, but not emphasized.” (Yağmur)

"It [iSTEM] tries to show what the result of the combination of these disciplines is. STEM explains the reason behind the phenomena. It shows us the intersection of two disciplines like chemistry and physics. It tries to explain where the junction of these two disciplines is. I think STEM will help us when there is a subject that is needed to explain by combining the two disciplines." (Ulaş)

After engineering design-based instruction three of the participants (Ekin, Ulaş, and Yağmur) were on common ground about that STEM disciplines should work together; they are interdependent and not be treated as separate entities. They argued that by promoting coherence between different disciplines, it would be easier to find solutions to real-life problems and have a better understanding of the concepts underlying each discipline. The following quotation exemplifies how interdisciplinary level of integration represented by participants:

"… We should not think STEM as a single discipline. STEM can actually be used to build a bridge between different science branches. What you learned in physics shows parallelism with what you learned in chemistry. For example, in order to understand movement of electrons, we need both mathematics and physics, we need interdisciplinary knowledge. Knowledge of different disciplines needs to be combined and understood to complete the system like in the activity." (Ulaş)

Interestingly, Deniz has taken one step further the level of integration by mentioning the developing solutions to real-world problems by using science, engineering and mathematics as well as using the practices of these disciplines to enhance the comprehension about them. The excerpt related to the transdisciplinary level of integration is as follow:

"To develop a project that eliminates the problems that we will encounter in our daily lives. While doing this, using scientific knowledge, developing a design based on scientific evidence, using some principles of disciplines, and being able to design like an engineer, to make calculations in other words making a design that will work properly. As a result, minimizing the problem, like air pollution or water pollution."

To sum up, the participants' expressions about the level of integration of STEM disciplines improved after performing the engineering design-based instruction. In other words, the participants deepened their explanations about the nature of integration of science, technology, engineering and mathematics and the role of integration of these disciplines to solve the real-life problems.

Regarding to degree of integration, no significant change was observed participants' statements. While content and supported content degree of integration between STEM disciplines indicated, participants did not put any proposition to degree of context integration (see Figure 4.5).

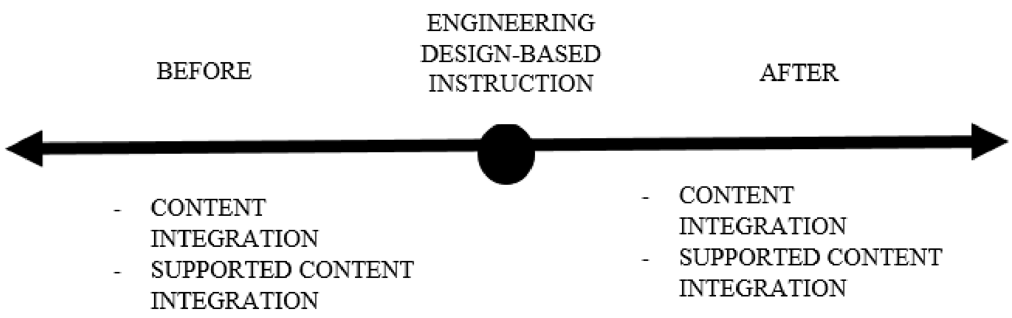

Figure 4.5 Degree of Integration STEM Disciplines Before and After Engineering Design-Based Instruction

Before engineering design-based instruction, three of the participants (Yağmur, Ulaş, and Ekin) have stated their opinions according to content, supported content, and context integration standards but one participant (Deniz) explained the integration with motivating students for engagement of learning. Data obtained from the participants surfaced mainly the content and supported content degree of integration. For instance, the following dialogue between the researcher and Ekin indicates how Ekin views content integration of disciplines in STEM:

"Researcher: Do you think that all four disciplines should be used in iSTEM?

Ekin: All four are very important issues, so why not?

Researcher: Do you think all of them should be included equally?

Ekin: I think it has to be on equal."

Another interviewee, Yağmur, said "For example, making project during the semester by using STEM. Making the project by using science, chemistry and mathematics. I think for high school, it could be something technological or a scientific experiment or project, like a project by integrating the lessons."

Whilst two interviewees mentioned content integration, one participant emphasized the supported content integration. The excerpt below shows how Ulaş explained the supported content integration:

"The subject we will cover limit us. There is a limit based on the parts of the subject that students should learn. I think the limit varies accordingly… I think integrating science and technology is more important than others right now, technology comes at first."

Collectively, two participants stated the degree of integration as content and one participant as supported content integration before they took engineering design-based instruction.

As distinct from the pre-interview, the participants made broaden explanations about the degree of integration of the disciplines. The participants who explained the content integration emphasized the equal importance of learning goals of each discipline. For example:

“The best thing is to use all disciplines together. It would be perfect to use all of them, but using two is actually enough.” (Yağmur)

“None of the disciplines in iSTEM is dominant, I think they have equally importance…. it can't happen without science, or it can't happen without technology.” (Ekin)

Supported content integration was expressed by the participants who underline the necessity of using the learning goals of peripheral disciplines to reach the learning goals of major discipline. To illustrate:

“It can be seen that the dominance of some branches increases at certain times while some of them decreases. There is no intention here to make them all equal. Some of them can be more dominant when needed.” (Ulaş)

In summary, these results show that Yağmur and Ekin stated the content degree of integration while Ulaş and Deniz indicated supported degree of integration for STEM disciplines. Although the participants of the study performed specific task about the environmental chemistry and practice the EDP, they could not express the situated learning environment and so context integration could not be achieved.

Representation of the disciplines in STEM is important to internalize the nature of iSTEM since required skills and knowledge of each discipline in STEM contribute to the way of integration of them. Before experiencing the engineering design-based instruction, three of the participants (Ulaş, Ekin, and Yağmur) have explained how science, technology, engineering, and mathematics were positioned in iSTEM as follows:

“Science” in iSTEM was described by two participants by giving the example of science topics like “We measure whether a reaction change is endothermic or exothermic…for example, we need to see the subatomic molecules,…” (Ulaş) while one participant indicated science as a discovery of facts or development of phenomenon by saying “Science can be directly like the discovery or development of something,…like the project that we did was a science,…" (Yağmur)

For "Technology" in iSTEM, two participants defined technology similarly by indicating it as animation/simulation and hardware and software of computer. The following statements which belonged to these participants clearly indicated their definitions of technology:

"…and that is mostly related with computers, things like software and hardware." (Ekin)

"We are trying to find approximately at least 200-250 equations for positions atoms, which cannot be perform manually… Technology helps us in this regard. For example, thanks to supercomputers, I can solve those equations for positions atoms." (Ulaş)

"…, perhaps animations in technology, chemistry animations, …" (Ekin)

"There are simulations. For example, we need to see the subatomic molecules, but we cannot, it remains very abstract. That's why we show simulations and help students get ideas thanks to technology." (Ulaş)

"For example, we need technological devices, such as thermometers. …" (Ulaş)

Another participant, however, proposed different definition for technology based on the production of utilities. This participant stated that "Science is directly like the discovery or development of something, technology is like putting science into production or any field that will make our lives easier…", "For example, the project was a science, the demand for buying the project is technology..." (Yağmur)

Three participants asserted "E" is an education, two of them have explained it in STEM integration. Interestingly, there were also differences in what "education" indicates in iSTEM for these participants. For example, Ulaş expressed the belief that "Education, I think teachers should improve themselves in terms of their behaviors…maybe their way of communication. For example, there are some teachers who know how to use technology, but they still want to use blackboard because they are used to it …Students want to learn on the smart board, but teachers try to do it in their own way. I think there is a need for change in this direction." On the other hand, Yağmur had point of view that focuses on teaching. The following excerpts involve statements she explained education in iSTEM:

"Science likes the discovery or development of something, technology likes its production or transferring it into a field that makes our lives easier, and education likes explaining science and technology, teaching them and conveying to the students how processes of science and technology works."

"For example, the project is science, and selling it was technology, and all the training that they received was education." (Yağmur)

The most striking result to emerge from the data is that participant who did not hear about STEM before, commenting about the "E" for engineering and expressing it in iSTEM as a constructing system which serves a purpose. The quote of participant's answer of meaning of engineering is provided below:

"For example, making a wheel or installing elevator system. I can think a system that works with specific purpose." (Ekin)

Two discrete answers emerged from how the participants define "mathematics" in iSTEM. Three of the participants indicated their ideas about what "M" in iSTEM means. One of the participants has expressed it as "method" while other two "mathematics." For the description of the participant who called "M" as "method;" science, technology and education were expressed in iSTEM whereas there were no traces of method for the integration of it with other areas. Other two participants propound the meaning of mathematics in STEM by stating it as calculation, formula, measurement, a mean of technology and science. For example,

"…there is a gas formula PV=nRT which can be used in mathematics…" (Ekin)

"It is a tool for calculation. Mathematics is a measuring tool; numbers tell the truth. By looking at the numbers, we create a logic and calculation …You reach technology and science through mathematics. The computer we use is a mathematical, cubic system. I think of mathematics as a foundation, a tool we use on that path…" (Ulaş)

Taken together, these results show that since three of the participants stated "E" as "education" in STEM, they explained it in the integration of the disciplines of STEM. One participant (Ekin) described engineering in iSTEM. Representations of science, technology, and mathematics in iSTEM were stated by participants without indicating their goals, practices and required skills for iSTEM.

After the participants have performed the engineering design-based instruction, the question "Can you explain how the disciplines in the iSTEM are used in the STEM activity you have done?" was asked to them to be able to elicit their definition about science, technology, engineering and mathematics in the context of iSTEM.

"Science" in iSTEM was defined by the two participants by referring the filtration system of the prototype. They declared that knowing physical and chemical principles was fundamental to construct the filtration system. To illustrate:

"How can we make the filtration? Directly, from our chemistry lessons it might be filtration methods, separation methods…it is generally related to the science in iSTEM. For example, we also used knowledge from physics, we used gravity." (Deniz)

"We had to know science to purify water and to establish the system." (Ekin)

There are expressions that pointed out the usage of scientific laws and theories as “science.” For example: “I think adhesion and cohesion, ...Then, we made the water flow using gravity.” (Yağmur) “As I said, science is the principles and theories we used while making a prototype.”(Deniz)

Distinctively, Ulaş explained what “science” is in general perspective and then stated that “science” set ground for obtaining better results for project by the help of the analysis of current situation with group members. The quote that includes related statements is provided below:

“We know science, we perform experiments, we get our data… When you look at the design, if you want to explain it logic behind it, you need to use scientific laws and principles. We need science while we discussing what went wrong or well in design and how we can make design better.”

For the definition of technology in iSTEM, limited data were obtained since the participants’ way of defining technology is generally about using of tools with power source for making prototype. For example,

“We actually tried to design a pump instead of water engine. We made a basic pump. This is actually a very simple technology…It is technology, even if it is the simple. In any technology, the water engine, or things we use in a design part to get help…” (Deniz)

One of the two participants, Ekin, who defined the technology as animation/simulation and hardware and software of computer, indicated the lack of use of technology while Ulaş described the technology as implementation of knowledge to reach more advanced levels. The excerpt that reveals his definition of technology as follows:

“Technology is a formation that promises opportunities to enhancements. It is accumulation of knowledge and its application…but since there is no concrete concept… we have formulated it, we turn it into a functioning system in our design, and we obtain technology.” (Ulaş)

Since "E" in iSTEM was attributed as "education" by most of the participants in the pre- interview, "engineering" discipline in iSTEM have been experienced with the engineering-based STEM activity by the participants. Three of the participants (Ekin, Yağmur, and Deniz) related the engineering with production of concrete outcomes. For example:

"For example, combining pipes. We tried to make a water pump, but we couldn't. It can also be considered as engineering…I would say machines as technology." (Ekin)

"Actually, what we really needed to do is to ensure that no air gets in the water pump. For example, there should be no air inflow or outflow into the pump. By providing air flow with the propeller system, we directed the air inside and so pressure was reduced the inside, ….We would make air moves from high pressure to low pressure. However, we could not create that pressure change because oxygen, that is, air, entered due to lack of material to cover surface of water pump. That's why we didn't have an engineering part." (Yağmur)

Deniz underlined the iterative process of engineering by saying "I think the design part, testing and building, these are included in engineering." Interestingly, Ulaş defined the engineering process of trial and error by linking it with technology and optimizing the system as follow:

"By applying technology, we also apply engineering. For example, how do we optimize technology while we are using it…In fact, engineering is implementation and optimization of technology…Engineering is needed for the optimization of the system… When we think about it in the field of physics, we tried to increase the potential difference. We realized that the height that we placed the filtration system was not enough, it should be higher position. Also, when the capillarity of the pipes is close, the time spent for the flow of water is shorter. That is why we shortened the length of the length of the pipe. We actually used such optimizations as engineering …"

In brief, most of the participants think that "engineering" in iSTEM is a process of developing products for problems.

About "mathematics" in iSTEM, the participants tended to define it through calculations. Examples from the participants' statements are provided below:

"We used mathematics for calculating the change in volume in time. We made a calculation based on how the amount of water in the tank changes over time. We made a calculation in the form of a certain ratio and proportion." (Ulaş)

"… Then we calculated the efficiency and used mathematics for it." (Yağmur)

Two of the participants, Ulaş and Deniz, emphasized the application of mathematics testing step of prototype. For example:

"Does the water flow in the system according to the criteria? We tested it and proved it with mathematics." (Ulaş)

"…we test them etc., but in order to do these tests, we need to go through certain calculations. There must be certain measurements. I think this part also is also related with mathematics." (Deniz)

In conclusion, performing the engineering design-based instruction resulted in the participants' possessing idea about disciplines that constitute STEM and how the design process is related with engineering.

4.1.2 The Change in the Pre-Service Chemistry Teachers' Opinions of STEM

Under this theme, "importance" and "limitations" are presented as sub-themes. Under the "importance" sub-theme there are codes that are "meaningful learning", "retention", "interest" and "workforce." There is also a code that is specific to the pre-interview; "21st century skills"; and the codes specific to the post-interview "time management," "communication skills," and "problem-solving skills" for the "importance" sub-theme. Meanwhile, "limitation" sub-theme contains "time consumption" and "tinkering" as codes of the data coming from the pre- and post-interviews.

"It makes students to love the lessons, and if students love lessons, they want to learn more…Maybe STEM could be something that focuses on the student's psychology. It might be something that makes students love the lesson rather than being anxious about lessons." (Deniz)

"For example, if I had awareness about the integration between the subjects of science branches before, my perspective on lessons would have been different… For example, I could understand how chemistry subjects are used in experiments, and if I had been given the opportunity to produce something by using scientific knowledge, maybe I would also be interested in research." (Yağmur)

The emphasis of meaningful learning is another conspicuous aspect when the participants mentioned about the importance of STEM. To exemplify:

"Of course, it is important since when I cannot connect the courses with each other, for example, molecular forces in chemistry with physics, because attraction-repulsion forces in molecules are related with electricity that is actually physics; when I cannot integrate them, I think them as separate disciplines. Since I think them as separate, I cannot have a map in my mind and after a while, I start memorizing them …Yes, we have a spiral curriculum in high school, we use the prior knowledge etc., but we are not given the value of this curriculum…Overlapping subjects between the disciplines and how these disciplines were used in practice should be described. That's why I think STEM is very important in that regard and should definitely be emphasized." (Yağmur)

In addition to "interest" and "meaningful learning," Ulaş put "retention," "workforce," and "21st century skills" forward as prominent expressions. He stated how STEM provides retention of knowledge by indicating that "When we think of STEM activity, student gains experience about how to apply knowledge and solve the problem. Student just needs to see the problem and then she can start immediately to produce solution since practicing STEM helps to remember how the problem was solved easily."

Ulaş also emphasized "workforce" for the importance of STEM in terms of raising students as a qualified workforce:

"Instead of teaching the students how they apply the formula, it is necessary to educate them how the formula works, that is, the logic behind the formation of the formula. Also, training the students as someone who are able to contribute the development of formula is important. Thanks to STEM, we can raise students who will learn the formula and advance it, rather than just using it."

Connected with "workforce," "21st century skills" was also underlined by stating:

"If we look at the last fifty or hundred years, there is a tremendous development in technology …, and we need to integrate it both in our way of thinking, our daily lives, and in our schools. Actually, technology is already integrated in these areas…I think STEM is a necessity of this era like integration of technology." (Ulaş)

Overall, it can be said that attitude of the participants toward STEM was positive since most of them perceive it as a medium for providing meaningful learning environment by revealing connection between disciplines as well as daily life and incentive that increase the interest of students for learning.

When the data that were collected after the engineering design-based instruction were analyzed, the most radical change in the statements of the participants was observed in the emergence of "problem solving skills" to emphasize the importance of STEM. Besides, the rich and thick data were obtained about "meaningful learning" in the post-interviews than the pre- interviews while the effect on "interest" of students towards learning expression was damping down.

All of the participants of the study mentioned about the “problem solving” as one of the substantial tenets that is provided for individuals with STEM. The thoughts of the participants about how “problem solving” skills were developed while handling with projects or situations in daily life are exemplified below:

“Students can do something by their own and gain experience with practicing STEM…When they encounter a problematic situation, they can say, “Okay, I can do something about this.” Like welding a plastic bottle with a silicone gun that we did in the STEM activity. We gain experience about handling with difficult situations…STEM is a great for problem solving skills.” (Deniz)

“You are becoming competent in problem solving skills...It may be daily life problem or problems that arise when making a project…” (Yağmur)

Like “problem solving,” the participants talked about the importance of STEM for “meaningful learning” from turning theory into practice point of view. To illustrate:

“Turning it into practice definitely…so STEM applications might be something that can be performed in the classroom because simple materials used for STEM applications.” (Deniz)

“…For example, students learn the topic but they rarely apply it or questioning what they have learned. STEM is trying to teach these to students in a more entertaining way…Students don't know where the formula is used or why the formula is written, they just apply it or write it mathematically. When they make the application of formula themselves, they actually become qualified students who know what they are doing and know the reason behind the things, and do not make memorization.” (Ulaş)

The other repeated expression in the interviews is “communication skills.” Two of the participants have demonstrated the importance of STEM by underlining the group discussions. To illustrate:

“Actually, we also worked as a group. Therefore, it also improves teamwork skills.” (Ekin)

“We had a discussion…STEM should be included in education to increase students' discussion skills and encourage them to explain themselves…They can defend themselves against the questions asked…There is cooperation and communication. We can express our opinions, listen to the others and criticize the ideas...STEM projects will definitely be better for students to explain themselves and express their ideas.” (Deniz)

When the post-interviews were analyzed, it was found that “interest” and “workforce” as the importance of STEM experience were indicated by the same participant similar to the pre-interview. The participant stated the important role of STEM on interest of individuals by explaining the active participance of the ones in their learning processes:

“Students lost their questioning abilities after a certain period of time because the lecturing is preferred as teaching method most of the time. Actually, STEM tries to teach subjects to students in a more entertaining way by involving them in the event like a game.” (Ulaş)

On the other hand, the importance of STEM as “workforce” was demonstrated in terms of creative and knowledgeable people:

“STEM is something that increases value of individual because of her knowledge, perspective and way of approaching the situations…To create a workforce, to create a quality workforce ...” (Ulaş)

“Retention” has also been mentioned while expressing the importance of STEM:

“…For example, let's say I [as a teacher] did a STEM project at ninth grade. I think they [students] will not forget the subject while they are preparing to the university entrance exam. I think they will remember the subject with a little repetition because they laid the foundation by making it themselves. They didn't just learn it in theory." (Deniz)

Another pattern that was spotted from the interviews was "time." Data revealed the duality nature of time for the participants so "time" has been examined under both sub-themes of importance and limitations. Under the sub-theme of "importance," it is named as "time management." To illustrate:

"For example, students will be able to learn how to manage time, experiencing STEM activity in limited time will be useful in the future for them. I think they gain a little practice for university or for their future careers." (Deniz)

On the other hand, sub-theme of "limitations" covers "time" from "time consumption" point of view. Three of the four participants (Deniz, Ekin, and Yağmur) have declared that the time required to perform the STEM activities was restricted for implementing it. For example, Ekin stated that "... People can do more things in the amount of time that spent for performing STEM. STEM confines the time at work."

As well as the "time consumptions," the participants have reported the "tinkering" as another limitation of STEM. For example, Yağmur expressed "tinkering" as:

"The students will only focus on working of the system. For example, we tried to produce something for four weeks, and the students generally focus on producing something like us. Everyone focuses on final product…Conducting STEM activity was not a process of learning, but a phase of producing something for us, and it will be the same for the student. I think they'll probably try to produce something instead of learning."

In conclusion, the participants stressed the importance of STEM by focusing on its promotion of problem-solving skills and meaningful learning as well as providing a medium in which multiple disciplines should be used in broader perspective. In contrast, time consumption was expressed by most of the participants as limitation of practicing STEM.

4.1.3 Summary of Results for the Change in the Pre-Service Chemistry Teachers' STEM Conceptions

Results of analyses of the pre-interviews revealed that most of the participants defined STEM as a student-centered method for education. Although half of the participants used "student-centered" and "method" predominantly in their definitions, "product," "project-based," and "use of scientific knowledge" were also preferred by the participants to express what STEM is. Before experiencing the engineering design-based instruction, one participant has defined iSTEM as a motivator for learning whereas three participants could not provide expression about iSTEM. Furthermore, the participants stated their propositions about the nature of integration of disciplines in STEM at disciplinary and multidisciplinary level while expressing the degree of integration in the form of content and supported content integration. In terms of opinions of STEM, the participants indicated that STEM might enhance the interest of individuals about the learning subject and promote meaningful learning. There are also expressions about it for increasing the retention time of knowledge. Its importance for workforce and gaining 21st century skills bring another perspective about the opinions of the participants toward STEM.

Results of analyses of the post-interviews showed that three of the participants pointed out the "based on real-life" as a key aspect in their STEM definitions. Also, obtaining tangible product at the end of the STEM activity was reflected the STEM definitions of the three participants. "Student-centered," "project based," and "use of scientific knowledge" are the other features of the STEM definition expressions of the participants after performing the engineering design-based instruction. The participants describe iSTEM by stating the steps of the EDP. They indicated that iSTEM contains engineering as a context for learning other disciplines and as a way of developing solutions for real-life problems. Level of integration of the disciplines in STEM was expressed at interdisciplinary level by three of the participants and at transdisciplinary level by one participant while half of the participants specified content and other half specified supported content for the degree of the integration. After the engineering design-based instruction, participants' opinions of STEM have developed. They indicated the importance of STEM to gain and enhance the problem-solving skills. In addition to this, it was found as significant medium for meaningful learning by the participants. Increasing interest toward learning subjects, developing communication skills, and contributing qualified workforce were determined as other features that indicate the importance of STEM. Yet, there are some limitations about STEM stated by participants. Period of time to perform the STEM activity found long by some of the participants and they also stated that performing the activity can transform from learning process to tinkering easily.

When the results of the pre-interviews are compared with the results of the post-interviews, it was seen that participants definition of STEM has changed from defining it as method to defining it based on the connection of real-life scenarios. Furthermore, after experiencing the engineering design-based instruction, the number of the participants who placed the "product" in their STEM definition increased noticeably. There are also differences between the participants' iSTEM definitions. Before implementation of the engineering design-based instruction, participants could not state definition for iSTEM but after instruction they proposed an iSTEM definition by emphasizing engineering design. There is a change in the level of integration of STEM disciplines based on the results of the pre-and post-interviews. The level of integration of disciplines iSTEM shifted from disciplinary and multidisciplinary level to interdisciplinary and transdisciplinary level. However, there is no change in the interview results according to the degree of integration of the STEM disciplines. Regarding to opinions of STEM, the participants' perception about the importance of STEM for meaningful learning developed. Additionally, they indicated the importance for problem-solving skills in the post-interview. Different than the pre-interviews, the importance of STEM in terms of increasing the interest of the students was indicated by a smaller number of participants while communication skill was added to indicate its importance in the post-interview. Furthermore, time consumption and tinkering were expressed as limitations of STEM in the post-interviews of the participants although there is no indication about the limitations of it before performing the engineering design-based instruction.

4.2 The Change in the Pre-Service Chemistry Teachers' Adoption of Self-regulation Through Engineering Design Process

The participants of the study were involved in think aloud protocol after conducting the engineering design-based instruction. The results obtained from the think aloud protocol was coded deductively to investigate the adoption of self-regulation based on the processes of self-regulation framework of Zimmerman (2000) and execution of the engineering design process (EDP) based on model of English and King (2015) and Moore et al. (2014) while dealing with STEM problem. The sections below propound the results of think aloud protocol under the themes of "Self-regulation" and "Engineering Design Process."

4.2.1 The Change in the Pre-Service Chemistry Teachers' Adoption of Self-regulation

Data obtained from the participants after they participated in the engineering design-based instruction were coded using Zimmerman's (2000) self-regulation framework. This section is devoted to draw a distinction between the participants' adoption of self-regulation process at the phases of forethought, performance, and self-reflection. Table 4.3 depicts the self-regulation processes adopted by the participants while proposing solution about how to upcycle of wastepaper for reuse with the EDP :

Table 4.3 Self-regulation Processes Adopted by the Participants

Phase	Process		Deniz	Ekin	Ulaş	Yağmur
Forethought	**Task Analysis**	Goal Setting	x	x	x	
		Strategic Planning		x	x	x
Performance	**Self-control**	Attention focusing	x		x	x
		Task strategies	x	x	x	x
		Self-instruction	x	x	x	
	Self-observation	Self-recording			x	
		Self-experimentation			x	
Self-reflection	**Self-judgement**	Self-evaluation	x	x	x	x
	Self-reaction	Adaptive/ defensive	x			

4.2.1.1 Forethought Phase

Forethought phase is the initial phase of self-regulation model of Zimmerman (2000) in which individuals set their specific goals and make strategic planning to achieve these goals. The data obtained from the verbatim transcripts of the think aloud protocol showed that the participants had tendency toward using task analysis processes. They did not indicate any statement about their self-motivational beliefs. Task analysis consists of goal setting and strategic planning. Three participants set goals before designing their system of upcycling. For example, Ulaş proposed the aim of the design by stating:

"Our problem is paper waste…We need to make use of the wastepaper well. Our problem is that we should use wastepaper to prevent paper waste. Not normal paper, but wastepaper. In order to produce as much as possible, I think we have pretty thin paper. You know, we should make organization to produce as much paper as possible and prevent waste of paper…I'm aiming for efficiency here. Indeed, I try to do more work with less material…"

Another participant, Deniz, not only expressed the aim of the design verbally, but she also noted the aim of the design by writing "filter system for paper upcycling."

Ekin, on the other hand, approached the problem by thinking about what exists at the beginning, and what is wanted at the end:

"First of all, I thought about the starting and ending points. At the beginning I have wastepaper and at the end I need to have an upcycled paper. It is reusable."

Three participants (Ekin, Ulaş, and Yağmur) also did strategic planning before drawing their designs. Two participants related their planning to their goals. The other participant, Yağmur, did not refer to the goal of the design while making planning; she read the headline of the task and then considered the available materials to make the design of upcycling system. She expressed it by stating that:

"First of all, okay, I probably need to turn the papers into mud at first by moistening them with water. This is similar to what I did when I was little. Then, probably with the help of a hammer, no, if I use enough water, the wire will be okay."

The other two participants also thought about the materials given to build an upcycling system and pointed out how these materials can be used. To illustrate,

"Lath and plywood…to close the filter, close it, cover it with these." (Ekin)

"I'm thinking about whether upcycled papers are given or not. Waste. Tulle, metal. It looks like something that is done for general needs. Paper production. Normally, I arrange the plywood and lath according to the desired dimensions." (Ulaş)

To sum up, most of the participants of the study set their goal and made strategical planning to achieve this goal by considering the available materials and limitations of the task.

4.2.1.2 Performance Phase

Performance phase involves the processes utilized during the action of experiencing the task. Self-control process contains sub-processes of self-instruction, imagery, attention focusing, and task strategies. Imagery was not performed by any participant whereas task strategies were experienced by all the participants. Task strategies in terms of explanation of the design process step by step was performed by all of the participants. Yağmur and Ekin explained their task strategies in similar manner. They have turned the wastepaper into paste, then constructed the strainer by using and pour the paste on the strainer to obtain an upcycled paper. The difference between their strategies aroused because of the way of creating paste and the material used for the construction of strainer. Yağmur obtained the paste by mixing wastepaper with water and constructed to strainer by using the tulle. Ekin, on the other hand, made the paste by mixing water with glue and constructed to strainer by using the mosquito net. Similar to Ekin, Ulaş also formed the paste by mixing wastepaper with glue, but he described how to obtain an upcycled paper without construction of strainer. The excerpt of Ulaş about the task strategies as follow:

"I grind the wastepaper at first. I cut it into as small pieces as possible, make the big size of paper into small form. Then I mix it with glue and turn it into a paste by ensuring pourable consistency…I pour this paste onto bowl that contains water and start to spread it by applying pressure with the plywood. Since there is water under bowl, when I turn paste upside down, it does not stick to the plywood, the paper comes directly into my hands."

Differently, Deniz proposed the steps of how to obtain an upcycling paper starting with increasing the motivation of individuals to throw out the wastepaper to the containers which are named based on the agenda of the day like which tennis player will the game. After that she has explained the steps as follow:

"Wastepaper comes to the main chamber with the help of a pipe there. It will start from there…. Those papers then come down and are collected in collection chamber. After that, there is a funnel-like shape construction. Its material needs to be something water resistant. Probably something is made with the help of wire, tulle and mosquito nets…"(Deniz)

Attention focusing is another sub-process that was used by three participants while designing their wastepaper upcycling systems. For example, Ulaş explained why he preferred to use bowl that contains water in his design by stating "When we press the paste, it spreads evenly. Let's think about it like this: When paste pour down, since it contains glue, it might stick to another material, and we will not be able to remove it." Additionally, he also stated why he preferred to use mosquito net instead of other materials like tulle "Since the mosquito net has a harder form than others, I preferred it for long-term usability. Since tulle is something that can be bent, its form might be damaged easily, and you can tear it I when you apply a little force on it. I found the mosquito net more suitable in terms of applicability.” Another participant indicated materials used in the construction of only specific parts of the system like “…rulers, scissors, cutters, glue etc. are used in frame construction.” Surprisingly, one participant focused on the appearance of the system and functionality without considering the properties of the materials:

“I thought wire would be better for funnel, but it could be made from plywood if it can be cut properly. I found logical to constructed it in the shape of a funnel because the papers will accumulate there, get wet, and get stuck in something there…” (Deniz)

Moreover, Deniz, Ulaş, and Ekin used self-instruction during the design of the system by asking questions themselves about the process. To exemplify, the question that Ulaş ask can be given “Do we have anything else to unify? As an adhesive, you can think of it as a mixture of ... adhesive?”.

Beside the controlling the progress toward goal, self-observation is another important process of performance phase. Self-observation can be experienced via self-experimentation and/or self-recording. Ulaş performed self-experimentation by testing thickness of the paste to increase the opportunity of obtaining the desired results. He explained the way of determining the amount of the paste by saying:

“…When I add the paste, how thick is it when I add how much from it? I give it a little test at first. I usually start with a small amount, and I adjust the quality of the paper accordingly…What I am trying to do here is the trial and error by adjusting the amount with my hands. Then, when the desired size and thickness is reached, I say this is the most suitable one and I keep this amount constant for paper production...”

In addition to the self-experimentation, one participant, Ulaş, used self-recording as a self-observation process by controlling what extent he meets the criteria of the system. He stated that:

“Equal, what we've already done is to have consistent thickness. Okay, it also needs to be thin. There should be no holes in the paper.”

Collectively, except imagery, all the processes of performance phase were observed in the data that was obtained by the think aloud protocol. However, number of the participants using self-observation processes obtrusively less than that of self-control strategies.

4.2.1.3 Self-reflection Phase

Self-reflection phase is the evaluation of the attained outcomes based on the desired goal after task was performed. All the participants of the study used self-evaluation that is one of the self-judgement processes. The participants employed the self-evaluation according to the criteria that were set for the properties of an upcycled paper from wastepaper such as thickness, dimensions, smoothness, etc. Some of the statements of the participants about self-evaluation based on the criteria as follow:

"I take the wastepaper and an upcycled paper… I can put these two on top of each other and look at them." (Ulaş)

"I will measure it with a ruler… I'll check if there are any holes in the paper, and if there is, I'll cover it with other papers, small pieces of paper and it will be equal and consistent." (Ekin)

Another process of self-reflection phase is self-reaction and only one participant, Deniz, indicated usage of adaptive strategies by giving the undetailed answer of "Then I'll upgrade this pattern a little bit" to the question "Let's say something happened to this machine and it went out, how do you compensate?".

To sum up, although adoption sub-process of self-judgement ;self-evaluation; by all the participants, usage of self-reflection processes of the participants is limited. Except the usage of adaptive sub-process by one participant (Deniz), self-reaction process was almost not observed among the participants.

4.2.2 The Change in the Pre-Service Chemistry Teachers' Implementation of Engineering Design Process (EDP)

The steps of EDP in the STEM problem about upcycling of wastepaper to reuse was coded using the models suggested by English and King (2015), and Moore et al. (2014). The denotations of "ask," "imagine," "plan," "create," and "test & improve" were used as codes. Table 4.4 summarizes the steps of the EDP followed by the participants:

Table 4.4 The EDP Steps Performed During Think Aloud Protocol

Steps of EDP	Deniz	Ekin	Ulaş	Yağmur
Ask	x	x	x	
Imagine				x
Plan	x	x	x	x
Create				
Test & Improve	x	x	x	x

4.2.2.1 Ask

The first step of the EDP that is "ask" about scrutinizing the problem and dividing it into sub-problems. Three participants examined the problem and reviewed the materials given for the solution of the problem by taking criteria and constraints into consideration. To exemplify, Ulaş conducted depth analysis about the problem by asking the questions as follow:

"What exactly is meant here now? It's very thin. It is produced by upcycling, that is, it is produced with recycled materials. A filter system, what kind of system is this filter system now?...What do you mean by filter system?...Will the quality decrease?"

He also highlighted the problem that he tried the find solution by saying "We need to use wastepaper to prevent excessive paper consumption. In order to produce as much upcycled paper as possible, rather than normal paper, I think it should be thin."

Likewise, Deniz and Ekin highlighted the problem by indicating the aim of the designing of the system. Deniz also review the criteria and constrains. She indicated them obviously in the following quote: "I mean, I just realized, by the way, I thought that dimensions of 7 to 13 is compulsory. It had to be at least 7 by 13. I wrote 7x13 here, but we can consider it as the minimum size then."

Moreover, Ekin has contemplated on the materials and how they could be used in the design of the system:

"Various sizes of mosquito net, tulle, string, wire that will most likely be used as something to separate large particles from small particles. Let me call it as a filter, I refer to it directly…Lath and plywood. Well, we close the filter with lath, we cover it with this. Ruler and compass, there's enough things to measure…What can I do with wastepaper using these materials? With scissors…but it can be cut into small pieces. Let's move on. The criteria are …"

To sum up, three of the participants approached the problem in the STEM task by considering the given materials and criteria so "ask" step of the EDP achieved by most of the participants.

4.2.2.2 Imagine

At the "imagine" step of the EDP, various ideas are generated within the boundaries of criteria and constrains. The data obtained from the participants revealed that three of them only concentrated on one design that came into their minds at first and did not think about any alternatives. Furthermore, they did not consider the strengths and weaknesses of their designs. One of the participants mentioned about usage of mosquito net instead of tulle because of its durability. Another participant also indicated how pipe in the design can be constructed by stating: “Even the strainer can be made with lath, it can be placed to make the corners and then surrounded with tulle, or it can be made from wire, or be made from plywood.” (Deniz)

However, none of these participants suggested different versions for entire of the upcycling system of wastepaper. Interestingly, one of the participants has drawn three possible systems for frame as shown in Figure 4.6:

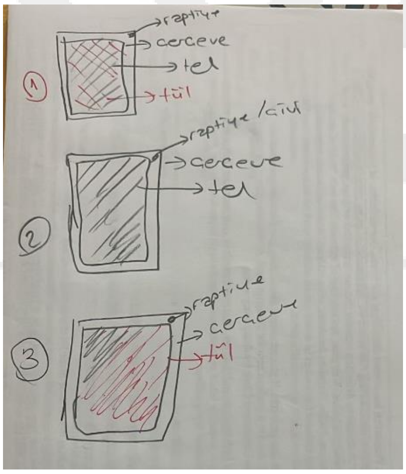

Figure 4.6 Frames for the Strainer Drawn by Yağmur

“I am currently drawing one of the possibilities of frame that is wire and tulle…Actually, I will try this by three different combinations. First, I draw the frame that is wire and tulle, but there is one more frame in which mosquito net and wire are used. I put them on top of each other with three different ways: tulle and tulle, mosquito net and tulle, and mosquito net and mosquito net. There are two layers, but I stretch them all." (Yağmur)

Since all of the system that she designed was based on strainer that is made from frames, in other words there is no other components of the system, her drawings set an example of "imagine" step of the EDP.

4.2.2.3 Plan

"Plan" is the step in which determination of the best design solution occurs and solution pathway is organized. Since the participants suggested one design for the problem, they explained not the best but only design solution for the problem. All the participants drew their design and explained it step by step. Their drawing of the design for an upcycling wastepaper to reuse is presented in Figure 4.7, 4.8, 4.9, and 4.10 for Deniz, Ekin, Ulaş, and Yağmur respectively:

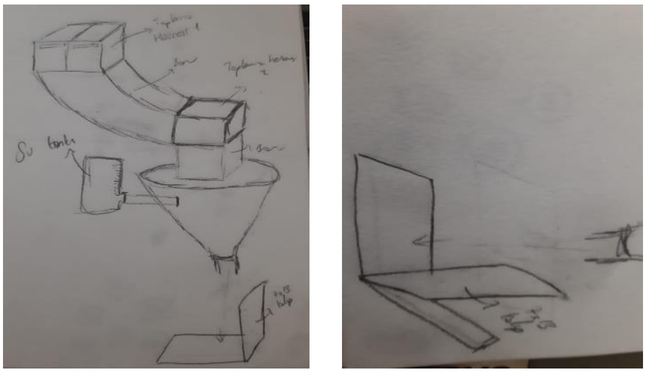

Figure 4.7 Wastepaper upcycling design of Deniz

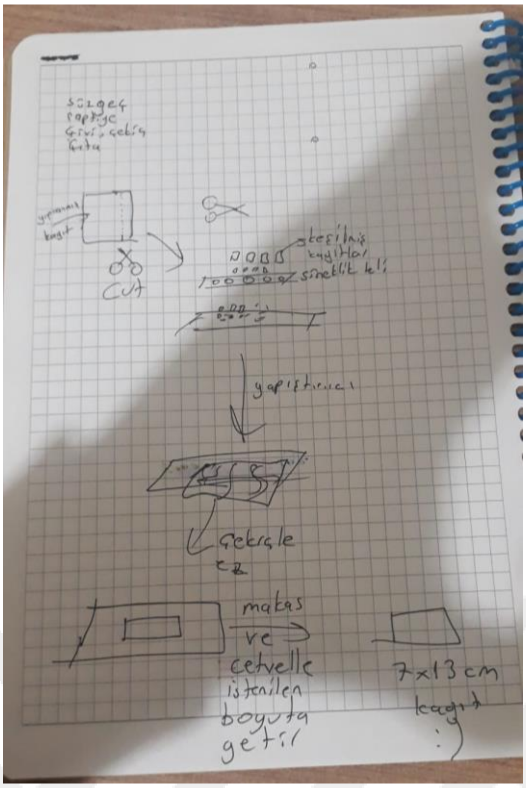

Figure 4.8 Wastepaper upcycling design of Ekin

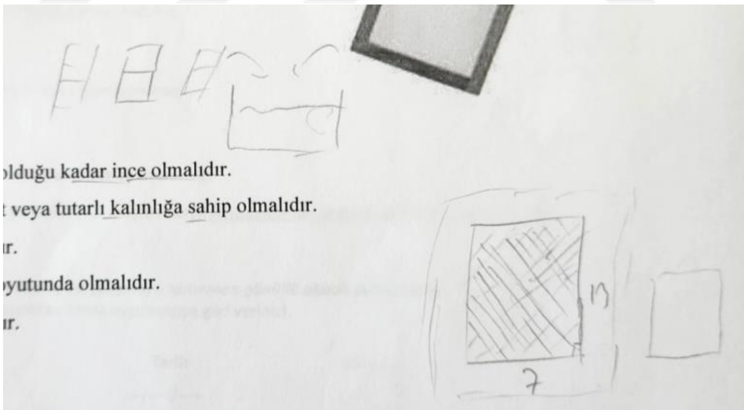

Figure 4.9 Wastepaper upcycling design of Ulaş

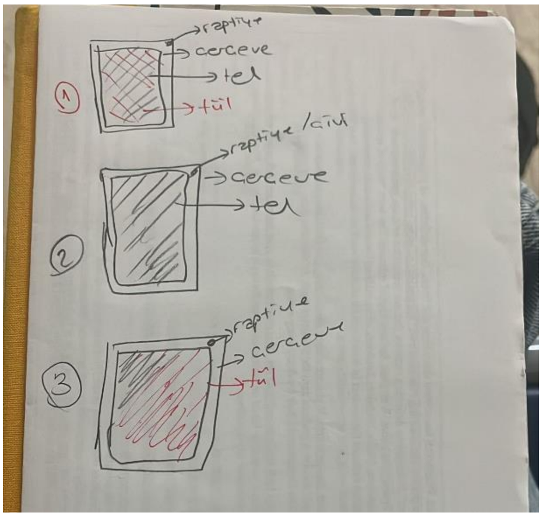

Figure 4.10 Wastepaper upcycling design of Yağmur

The common points of the explanations of the participants about their system designs were that the participants did not present how the thickness of an upcycled paper was confirmed, and they did not enlarge on the parts of their designs in terms of material preferences. All participants mentioned about turning wastepaper into the paste; however, they did not explain the ratio of the ingredients to make the paste. Overall, the participants' explanations were lack of details in preparation of paste of wastepaper, construction of strainer and demonstration of thickness of an upcycled paper. Some excerpts indicated below explain this situation:

"Since it is a mosquito net, I can achieve the thickness that I want. The pores are completely closed when I apply pressure. In this way, I can obtain the paper that is thin as much as I want." (Ulaş)

"…It doesn't matter if these are nails, hammers, thumbtacks, whatever. I wrote pins here and I'm fastening with them. Then I pour the paste into frame, and then spread it 90 degrees and 180 degrees, that is, horizontally and vertically. I dry the paste. During this drying process, I will probably stretch a wire over it…"(Yağmur)

On the other hand, all of the participants divided their system designs into two steps: preparation of paste of wastepaper and fit it into dimensions stated as criterion. In the light of these main headlines, they have explained their systems in logical order. For example,

"I grind the wastepaper at first. I cut it into as small pieces as possible, make the big size of paper into small form. Then I mix it with glue and turn it into a paste by ensuring pourable consistency… I pour this paste onto bowl that contains water and start to spread it by applying pressure with the plywood. Since there is water under bowl, when I turn paste upside down, it does not stick to the plywood, the paper comes directly into my hands." (Ulaş)

Overall, the participants introduced their system design in logical order but there is a need for details to build the systems that they described.

4.2.2.4 Create

Since the participants have demonstrated their designs on paper, prototype of their systems was not available. Nevertheless, material preferences and lack of descriptions of how to build some parts of their systems give the clue about possibility of working of these systems. To illustrate, in her design, Deniz built water supply tank by using hydrophilic material of plyboard and it was attached to the funnel without support. Yağmur could not explain the specific method for making the paste dry increases the possibilities of problems in the prototype since she said: "Yes, paste will flow because it is a liquid and there is a gravity."

4.2.2.5 Test & Improve

Because the plan of the design of the system was on paper, testing prototype is not practical. Therefore, the question "How will you test your system's compliance with the criteria?" was asked to the participants. Ulaş and Yağmur stated process of trial and error to control whether the system meet the criteria or not. To exemplify;

"Yes, but paste will probably fit the frame through the wires,…so I will do it by trial and error method. I am currently drawing the possibilities of the frame of wire and tulle….The wires stand as an additional support. To prevent flow of paste, I test tulle-wire and tulle-wire frames whether it stays between wire and tulle or not. For example, when frames are horizontal at 90 degrees, that is, when it is horizontal to the ground, will it stay in between, or will it flow? When it is 180 degrees, for example, will all the paste flow down or not?" (Yağmur)

Moreover, one of the participants indicate the usage of measuring tools by stating: "For example, I measure the dimension of paper with a ruler…" (Ekin)

After the participants answered the question about "test" of suitability of their design based on the criteria, the question "If your system does not meet the criteria, how will you make it comply with the criteria?" was asked to reach the data of "improve" step of the EDP. Ekin and Yağmur answered this question superficially as shown in the following dialogue between the researcher and Ekin, and Yağmur's excerpt, respectively:

"Researcher: For example, if it does not meet the paper thickness criteria, how do you make it in appropriate thickness?

Ekin: There are two things then, there are two problems, either the hammer isn't crushing well, or I didn't crush it enough. First, I try to crush it a little more with a hammer. If I saw that it doesn't work again, then I won't use a hammer."

Yağmur answered "If there is a hole in the paper, I will try to find the one that does not have holes. If there is a hole, obviously I need to try a second method."

When the question about the existence of pores in the paper was asked, Ulaş answered it by bending the criterion of thickness of paper: "I optimize the system, I put more wastepaper, and increase the amount of paste. I would have increased the thickness slightly, but at least there would be no holes."

Beside these answers, Deniz explained how she handled if there are holes in the paper by explaining the construction of new strainer system in detailed as follow (see Figure 4.11):

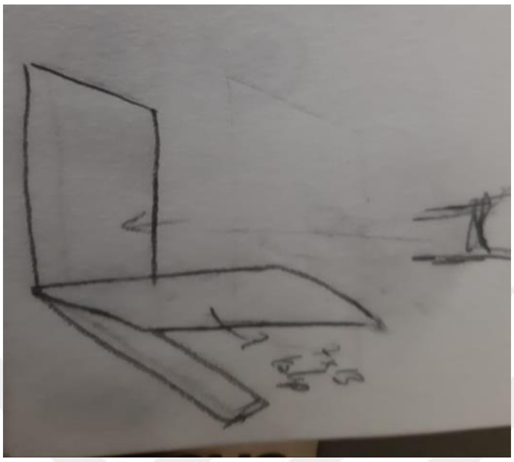

Figure 4.11 Strainer System Drawn by Deniz to Meet the Criteria of the STEM task

"…The plastering is exactly the same on the paper, its thickness will not change. After all, only plastering can fill the holes…Since plywood will be heavier, it increases the possibility of less spreading compared to tulle and wire. Therefore, I think making covers in the strainer from plywood will reduce the holes in the paper….Actually, it can be made with two covers. Come to think of it, I could make two covers. When the cover lands, it will overlap with the other. In other words, like a gate here and there, …"

Overall, it can be said that explanations of the participants about fulfilling the criteria of the STEM task shows a necessity of more systematic approach than trial and error.

4.2.3 The Change in the Pre-Service Chemistry Teachers’ Adoption of Self-Regulation Processes Through Implementation of the Engineering Design Process (EDP)

The think aloud protocol provided the data about the implementation of the EDP and adopted self-regulation processes by the participants throughout the implementation of the EDP. The data about the EDP were coded using the model of English and King (2015) and Moore et al. (2014) while Zimmerman’s (2000) self-regulation framework was employed for the analyses of the data about self-regulation. Table 4.5 explains the self-regulation processes used in the steps of the EDP:

Table 4.5 Self-regulation Processes Observed During the Implementation of STEM Task in Think Aloud Protocol

STEPS of the EDP	ASK	IMAGINE	PLAN	CREATE	TEST & IMPROVE
PHASES of SELF-REGULATION	Forethought		Performance	x	Self-reflection
PROCESSES of SELF-REGULATION	Task Analysis (goal setting and strategic planning)		Self-control (attention focusing, task strategies, self-instruction)	x	Self-judgement (self-evaluation)
			Self-observation (self-experimentation)		Self-reaction (adaptive/defensive)

The data analyses revealed that most of the participants implemented the sub-process of task analysis at the forethought phase of self-regulation while dealing with the “ask” and “imagine” steps of the EDP. Task analysis process of goal setting was used by Deniz, Ulaş, and Ekin while strategic planning was practiced by Yağmur, Ekin, and Ulaş at the “ask” step of the EDP. Yağmur also applied strategic planning at the “imagine” step of the EDP. For example, when Ulaş read the problem of upcycling wastepaper at the “ask” step of the EDP he performed the goal setting by saying “Our problem is paper waste…We need to make use of the wastepaper well. Our problem is that we should use wastepaper to prevent paper waste. Not normal paper, but wastepaper…” Another participant, Ekin, made strategic planning by determining which materials would be used for the specific purposes in the system design for upcycling like using lath and plywood as a cover for the filter while reading the materials given at “ask” step of the EDP. On the other hand, Yağmur also used strategic planning at the “imagine” step while generating multiple ideas for solution of wastepaper problem.

The participants adopted the sub-processes of self-control and self-observation at the performance phase when they were working on the “plan” step of the EDP. Self-control process of task strategies were applied by all the participants while they were explaining how they upcycle a wastepaper in stepwise manner at the “plan” step of the EDP. Except Ekin, other participants used attention focusing to indicate the reasons of their choices about their designs. To exemplify, Deniz explained why she preferred to used funnel shape in her design by stating that “… I found logical to constructed it in the shape of a funnel because the papers will accumulate there, get wet, and get stuck in something there…” Self-instruction was also experienced by the three participants (Deniz, Ekin, and Ulaş) at the “plan” step of the EDP by questioning their choices about materials like “…Do we have anything else to unify?...” (Ulaş) Although the processes of self-control which are task strategies, attention focusing, and self-instruction were adopted by most of the participants, self-recording and self-experimentation as the processes of self-observation was employed by one participant (Ulaş) at the “plan” step of the EDP. He used self-experimentation for explaining determination of thickness of paper and self-recording for checking the thickness of paper based on the criteria. However, “create” step of the EDP was not performed by the participants so the self-regulation processes related with the “create” step of the EDP cannot be provided. Yet, the participants’ material preferences to construct a prototype like making water tank by using hydrophilic material might show their deficiency of using self-regulation sub-processes of performance phase. For example, questioning of the durability of material might show the lack of attention focusing and searching for the alternative materials for construction of prototype might be related with their deficiency of adoption self-instruction.

All of the participants carried out the self-evaluation sub-process of self-judgment while examining the appropriateness of their designs for the solution of wastepaper problem based on the criteria at “test & improve” step of the EDP. To illustrate, Ekin stated that “I will measure it with a ruler… I'll check if there are any holes in the paper, and if there is, I'll cover it with other papers, small pieces of paper and it will be equal and consistent.” There is also one participant (Deniz) who performed self-reaction process with adaptation at the step of “test & improve” by asserting to continue to design a system for the upcycling a wastepaper by changing the part of the system that does not meet the requirements of the criteria of the task.

4.2.4 Summary of the Change in the Pre-Service Chemistry Teachers’ Adoption of Self-regulation Through Engineering Design Process

When the think aloud protocols of the participants were analyzed based on the self-regulation framework of Zimmerman (2000) it was seen that processes of performance phase were adopted more than the forethought and self-reflection phases by the participants. In the forethought phase, task analysis process was prominent among the participants while codes for self-motivation beliefs did not appear. Three of the four participants declared the usage of task analysis sub-processes that are goal-setting and strategic planning while expressing how they design their system. As for the performance phase, self-control processes were preferred more than self-observation processes by the participants of the study. Of the self-control processes, attention focusing, and self-instruction were seized on by three of the four participants while all the participants have used the task strategies. On the other hand, data related to self-observation process were obtained from two participants who utilized self-experimentation and one participant who used self-recording. Moreover, the implementation of self-evaluation sub-process by all the participants brought out the self-reflection phase. Although, all participants used self-evaluation of self-judgement process in the self-reflection phase, none of the participants uttered the statements related to causal attribution as a self-judgement indication. Similarly, other process of self-reflection that is self-reaction could be traced only as adaptive/defensive sub-process in one participant's explanations while there was not any expression about self-satisfaction/affect sub-process.

When the data of the think aloud protocol was analyzed with respect to how much participants adhered to the steps of the EDP, the "ask" step was appeared in three participants' explanations. All of three participants examined the problem based on the materials and the criteria. However, the second step of the EDP that is "imagine" was performed only one participant (Yağmur). She suggested three different frames for the strainer system while other participants only focused on the one design solution for the wastepaper problem. In terms of the "plan" step, all of the participants explained their design by dividing it into two main sections: preparation of paste and obtaining paper with respect to criteria of the task. Although they explained how they turned wastepaper into an upcycled paper step by step, the details like the amounts and the dimensions of the constituents of their design were missing. "Create" step of the EDP was not applied by any of the participants. They did not describe how the process of design would work in the real-life scenarios. On the other hand, all of the participants engaged in the "test & improve" step by indicating their actions to handle with the holes in an upcycled paper and how they adjust the thickness and the dimensions of a paper to meet the given criteria. Moreover, one participant (Deniz) suggested a new strainer system to produce ta paper as it demanded in the task.

Analyses of the data about adoption of the self-regulation processes throughout the experience of the STEM activity put forward that "ask" and "imagine" steps of the EDP might exhort the implication of the task analysis process of forethought phase that are goal setting and strategic planning by most of the participants. “Plan” and “create” steps, on the other hand might promote the usage of the process of performance phase. All of the participants applied the task strategies and three participants used attention focusing and self-instruction sub-processes of self-control while self-observation sub-processes of self-recording and self-experimentation was practiced by one participant (Ulaş). The data about “test & improve” step revealed that all of the participants exerted self-evaluation as self-judgement sub-process at self-reflection phase while self-reaction sub-processes were barely seen.

CHAPTER 5

DISCUSSION

This chapter concerns with the discussion of the results under the sections of the role of engineering design-based instruction on STEM conceptions and adoption of self-regulation processes by the pre-service chemistry teachers After that, conclusion of the results, implication for practice, and recommendations for further research are presented.

5.1 Discussion of The Results

To achieve the purpose of investigation of engineering design-based instruction in terms of STEM conceptions and adopting self-regulation by the pre-service chemistry teachers, basic qualitative research design was utilized. The results that were emerged from the interviews and think aloud protocol shown that implementation of STEM education based on the engineering design process (EDP) can provide suitable environment for the pre-service chemistry teachers both for fostering the growth of STEM conceptions and adoption of self-regulation processes. Therefore, the role of the engineering design-based instruction in STEM conceptions and adoption of self-regulation processes by the pre-service chemistry teachers will be discussed separately as follows:

5.1.1 Discussion of The Role of Engineering Design-based Instruction on The Pre-service Chemistry Teachers' STEM Conceptions

This section of the discussion chapter is devoted to discussing the results of examining the impact of the EDP on the pre-service chemistry teachers' descriptions and opinions of STEM.

Firstly, analyses of the results based on the description of STEM uncovered that the implementation of the EDP improved the conceptions of the participants about STEM. While the participants could not declare the disciplines that made up STEM before, they indicated the names of all disciplines correctly after the implementation of the EDP. Although the results of the pre-interviews align with the literature reporting that people who study in certain fields elucidate the abbreviation of STEM through terms specific to their field like teachers who have explained the "education" as "E" part of STEM abbreviation (Bybee, 2010), the results of the present study showed that this tendency of the pre-service chemistry teachers might evolve into correct name of disciplines by the help of implementation of the EDP. However, meaning of the disciplines in STEM is more than stating the denotations of the letters in STEM abbreviation. For this reason, to enhance the depth of analysis concerning the participants' knowledge in STEM and their comprehension of the interdisciplinarity inherent of integrated STEM (iSTEM), meticulous attention should be devoted to their delineation of the constituent disciplines comprising STEM.

The results of the study show that participants' definition of science, technology, and engineering mounted after implementation of the EDP while mathematics did not markedly change. A possible explanation for the result of mathematics might be related to the place of it in the STEM activity; it was a mean for reaching to final product not application of mathematical modeling (Just & Siller, 2022; Salinger & Zuga, 2009). Consistent with other research studies which revealed common role of mathematics in STEM as a minor issue (Ding & Cai, 2023; Just & Siller, 2022; Maass et al., 2019), in the drip irrigation system that the participants designed in this study, mathematics was only used for calculation of the number of drips per minute and measurement of the distance. Since there is not an obligation for practicing all STEM disciplines in every STEM learning experience equally (Kelley & Knowles, 2016), the pre-service chemistry teachers may not perceive the role mathematics in the STEM activity of this study.

In contrast to mathematics, participants have particularized their general descriptions of science, technology, and engineering after practicing the EDP. This finding is in agreement with the studies which show that utilization of series of engineering design-based activities enhance pre-service science teachers' understanding of science (Capobianco et al., 2022; Ozkızılcık & Cebesoy, 2023). Practicing the EDP through drip irrigation system also enlarged the technology definition of the participants by the addition of "tool" that was used to build the system. This finding corroborates the ideas of Ring-Whalen et al. (2018), who suggested that technology is used as tool or supporter for engineering activities. Another possible explanation rather than usage of utilities for this result might be the active engagement of the participants in learning process. Becoming an active participant might be advanced their definition in terms of both constructivist and traditional uses of technology (Teo et al., 2008).

Among STEM disciplines, engineering was the one that the participants exerted themselves to define it most due to their lack of knowledge about "E" in STEM abbreviation before practicing the EDP. After implementing the engineering-based STEM activity, the participants defined engineering as a process of production of concreate outcomes which are developed as a solution for a problem. When compared to the definition of engineering in previous studies, the participants' definition of engineering displays similarities with them from the aspects of providing benefits for the world by proposing solutions for problems residing in logic and creativity (Salcedo et al., 2024; The American Association for the Advancement of Science, 2009). This result might be aroused because of the framework that the participants followed while building their prototype. The scenario given to the participants requests from them acting like engineers to construct the drip irrigation system in permaculture area by flowing the steps of design process. Therefore, qualifications of engineers such as making innovations and developing existing processes and/or products to meet the demands of society might be internalized by the participants and resulted in fitting their engineering definition into literature (Brophy et al., 2008). This also accords with earlier findings in the literature in which pre-service teachers' perceptions of engineering and engineering design is composed of building or fixing machines (Hammack & Ivey, 2016; Kuvac & Koc, 2022). While designing their system, limitation of using basic materials compelled the participants to think about the alternative solutions. For example, they tried to make propellers in different sizes by using materials like bottle caps, adhesives etc. This process was also reflected how they define engineering by giving place the aspects of the EDP that are iterative nature and process of trial and error. A possible explanation for the emphasis of iterative nature of engineering might be that higher level of integration among STEM disciplines could be possible when engaging in the EDP thanks to the utilization of science and mathematics instead of following list of standards about these disciplines (Berland, 2013).

Secondly, after the abbreviation and descriptions of the disciplines in STEM, the definition of STEM was asked to participants for framing their understanding of STEM terminologically. There are common descriptors "student-centered nature," "project-based approach," and "usage of scientific knowledge" for defining STEM. These terms for defining STEM might arouse because of the participants' freedom in the construction of prototype in the EDP. The participants were responsible for their own design process and decided which scientific theories and laws to use in creating the prototype. Therefore, the inclusion of scientific knowledge to explain the logic behind the prototype's working principle, working without expert help, and collaborating as a team to create a tangible product may be the reasons why they included these terms in their definition of STEM. "Student-centered," "project-based," and "usage of scientific knowledge" listed as descriptors for defining STEM before taking the engineering design-based instruction. Although the participants also used these descriptors after the implementation of the EDP, taking the engineering design-based instruction enhanced their understanding about these descriptors due to the experiencing all process at first hand. For example, meaning of the "project-based" shifted to emphasize on product to on process which accords with earlier studies which showed that engineering-based activities were directed to project-based learning mostly due to the importance of the process as much as obtaining product in the project-based learning activities (Dare, 2021; Lynch et al., 2014; Sahin, 2013). Another salient result of the study is that the participants' tendency of putting emphasis on "product" become widespread for defining STEM after practicing the EDP. A possible explanation for this might be that creating prototype at the end of the EDP echoes conversion of theoretical knowledge into practice due to the nature of engineering (Deniz et al., 2019; Yu et al., 2019). In accordance with the present results, previous studies demonstrated that pre-service teachers possess the idea that tangible products are significant element of engineering to define STEM (Faikhamta, 2020; Mumba et al., 2022).

The most remarkable change observed about the definition of STEM was fading away of description of STEM as "method" and portraying STEM as reflection of "real-life situations" after performing the STEM activity. The fact that the expression "method" was included in the participants' first definitions might be related to the fact that this study was conducted within the scope of the teaching methods course. Following the steps of the EDP while performing the STEM activity might play a role for the elimination of "method" in STEM definitions of the participants. Moreover, conducting the EDP to seek solution for universal problem; drought; in local scale, might be the reason of encountering with "based on real life problem" in their definition of STEM. This result of the present study is consistent with those of the findings of other studies, in which dealing with real-life problems was a rationale behind STEM (Erdogan & Ciftci, 2017; Maiorca et al., 2023; Pimthong & Williams, 2018). Overall, performing the STEM activity tended to enhance STEM definition of the participants in terms of giving place to "real-life problems" in their definitions and amplify the project-based nature that was harmonized with the definitions of Breiner et al. (2012) who stated STEM as educational strategy of project-based approach and integration of the curricula of STEM disciplines based on the real-life problems.

Thirdly, when the statements of the participants were scrutinized it was found that because they were unfamiliar to iSTEM before exposing the engineering design-based instruction, the participants were unable to articulate what it is. After implementation of the STEM activity, the participants explained the iSTEM by using the EDP as glue between the disciplines and a key for solving “real-world problem.” Their definitions suit with the explanations of Moore and Smith (2014) which propose the existence of natural connection between the STEM disciplines and real-world problems and Bryan et al. (2015) who emphasize the importance of practices of engineering and engineering design for the integration of disciplines. Likewise, Menon et al. (2023) reached out that pre-service teachers described iSTEM as cohesive learning model that promotes problem solving skills thanks to dealing with real-world problems. Although, this result differs from some studies (e.g., Nugraha et al., 2023) that revealed pre-service teachers’ tendency toward practicing science for integration and engineering as complementary, it is in line with results of Lin et. al’s (2021) study which show knowledge of pre-service teachers about the EDP is enhanced when design process has infused into STEM project-based learning.

The improvement in the explanations about the STEM disciplines and EDP paint a promising picture about the participants’ approach to the nature of iSTEM after taking part in the STEM activity. The results of this study indicate that expressions of the participants about the integration of disciplines showed a trend toward higher level of integration from disciplinary and multidisciplinary levels to interdisciplinary and transdisciplinary levels. It seems possible that remarkable change between the level of integration of disciplines might arouse due to the participants’ limited exposure to STEM before the enginnering design-based instruction provided in this study. Another possible explanation for these results may be related to the interdependence of science and engineering, and association between engineering and technology in the design process of drip irrigation system. Combining knowledge generation and application of scientific rules with technical action thanks to the isomorphic structures empirical research and design process might contribute the sense of higher level of integration among STEM disciplines (Eekels & Roozenburg, 1991). This also accords with earlier studies, which show that the pre-service teachers define the well-connected integration level among STEM disciplines when they experienced the EDP (Aydın-Günbatar et al., 2021; Çeliker, 2020; Pimthong & Williams, 2021; Wu et al., 2021).

Beside the level of integration, results of the study were also examined with the lens of the degree of integration. It appeared that there was a significant aggregation of content and supported content integration to explain the connection between STEM disciplines. The STEM activity about the "drip irrigation system" that was served to the participants covered the objectives of "water and life" for chemistry and "understanding steps of design process" for engineering disciplines primarily. Therefore, it is not surprising that half of the participants perceived that attainment of the objectives of more than one discipline were achieved at the end of the activity. The content integration tendency of the participants in this study shows similarities with the studies of Correia and Baptista (2022) and Rinke et al. (2016) in which the importance of content integration of STEM disciplines by pre-service teachers specifically underlined. On the other hand, it is also welcomed to reach the supported content integration approach from half of the participants since they might deduce the role of engineering in the activity as a mean of attaining objectives of chemistry curriculum due to the lack of specific objectives of engineering at K-12 level.

Finally, opinions of STEM of the participants towards STEM education have been examined. Upon investigating the data of the participants who practicing the engineering-based STEM activity, it was found that all of them believed STEM would be beneficial to develop problem-solving skills and enhance meaningful learning. It was not surprising prominence of meaningful learning and problem-solving skills together to designate the importance of STEM education by the participants since the STEM activity that the participants conducted demands the application of scientific principles in the context of engineering design to solve the problem for water deficiency with the design of drip irrigation system. Therefore, they had first-hand experience about the how scientific principles works for solving real-life problems like by using the knowledge of filtration technique to obtain the clean water for the drip irrigation system. Combination of disciplinary knowledge and cognitive processes for problem-solving helps actualization of meaningful learning (Mayer, 2002). Furthermore, this study produced results which corroborate the findings of a great deal of the previous work in this field in terms of perceptions about STEM education as providing a way of connection between the school subjects and real-world cases (Fitriyana et al.,2023; Sutaphan & Yuenyong, 2021; Sandall et al.,2018). Parallel to the learning STEM subjects meaningfully, the participants also stated their ideas about the permanence of the knowledge gained by application the engineering-based STEM activity. This result may be explained by the fact that performing the STEM activity evokes the activity-based learning in participants because of their common ground that is learning-by-doing (Skulmowski, 2024). Therefore, participants might deduce the long retention time of knowledge after implementing activity like in the activity-based learning (Answer, 2019;Ashfaq, 2020).

"Enhancing interest" was another striking finding that the pre-service teachers stressed about the importance of STEM education in the pre-and post-interviews. The participants of the study stated that STEM might create alternative for learning the school subjects more enjoyably since designing process was fostering hands on, hearts on and minds on activities which in turn might arouse interest (Cassim, 2013). The result of this study is parallel with the studies that claim that fostering STEM education on covering the subjects plays a role on developing interest of pre-service teachers (Calderon et al., 2019; Kim et al., 2015; Oktay et al., 2023).

In addition to the descriptors which can be correlated with learning of STEM disciplines, data obtained from the participants revealed the statements which serve the emergence STEM education: constitution of workforce qualified for meeting the demand of 21st century with the specific emphasis on the development of communication skills. Since the participants worked as a team in making division of labor and discussions about how they operate the system, they indicated the importance of communication that is one of the 21st century skills. These finding supports previous research studies which link STEM education and 21st century skills. Reserach studies put forth the constructive contribution of STEM to reach the goal of equipping students with the 21st century skills such as collaboration and communication to raise qualified workforce (Djulia & Simatupang, 2021; El-Deghaidy & Mansour, 2015; Hacıoglu, 2021; Hatisaru et al., 2019; Kartal &Tasdemir, 2021).

In contrast to the contributions of STEM education mentioned above, the participants of this study also presented their worries about the implementation of STEM education. The participants stated that implementation of the STEM activity requires long period of time so it cannot be finalized in a couple of lesson hours. Therefore, the participants indicated that the STEM activities can be performed out of school time. The present findings seem to be consistent with other results which stated that time constraint was seen as limitation of application of the STEM activities due to demanding careful time management for the preparation and implementation (Büber, 2023; Kanadlı, 2019; Stubbs & Myers, 2016). Beside the consumption of time, the participants indicated the risk of not being able to transcend the tinkering while generating product during the STEM activity. The participants stated the possibility of experiencing difficulty in focusing on the main goal of the activity and correlating the laws and theories with the preferences related to the design of system as well as possibility of randomness in the success of the design. This finding of this study corroborates earlier findings which also highlighted that the STEM activity should be go beyond the tailoring and tinkering by redesigning methodologies. To realize its goal as a constructivist innovative strategy, individuals should construct their own understanding by using their critical thinking skills in hands-on activities through collaboration with others (Gough & Gough, 2018; Vossoughi & Bevan, 2014).

5.1.2 Discussion of Adoption of Self-Regulation Processes by The Pre-Service Chemistry Teachers

This part of the chapter discusses the role of the engineering design-based instruction on adoption of self-regulation processes by the pre-service chemistry teachers. Based on the pre-interviews, which were conducted at the beginning of the study to determine the pre-service teachers' general habits of learning and studying, it can be said that the pre-service chemistry teachers possessed external regulation, as they expressed a need for instructor guidance to organize their study (Boekaerts, 1999). Conversely, the findings of the think aloud protocol which was conducted at the end of the study to explore participants' adoption of self-regulation processes in the STEM task showed that they used multiple self-regulation processes to find a solution for the given STEM problem. This finding seems to be consistent with other research studies that proposed that intervening self-regulation in STEM education can enhance STEM learning and break down the poor self-regulation cycle (Blackmore et al., 2021; Rutherford et al., 2018).

There are plenty of EDP models in the literature which highlight essential steps: defining problem, setting solution for the problem, and optimizing the solution. In addition, the iterative nature is central to the EDP (Arık & Topçu, 2020; Daugherty & Carter, 2018; Dym et al., 2005; NGSS, 2013). These fundamental features of the EDP particularly with its iterative nature show similarities with Zimmerman's (2000) self-regulation model (Zheng et al., 2020, 2023). In the self-regulation model, major phases are executed with the aim of setting goal of the learning task and making strategic planning; performing the task; and evaluating performance in a cyclical manner. The findings obtained in the present study mirror those of the previous studies that examined the steps of the EDP and self-regulation jointly. The EDP employed in this study included ”ask,” “imagine,” “plan,” “create,” and “test & improve” steps (English &King, 2015; Moore et al., 2014). The adoption of self-regulation processes in the context of the EDP was manifested as: goal setting and strategic planning (task analysis process/forethought phase) in the “ask” step; task strategies, attention focusing, and self-instruction sub-processes (self-control process/performance phase) in the “plan” step; and self-evaluation sub-process (self-judgement process/self-reflection phase) in the “test & improve” step.

Before performing the STEM activity, the participants stated that the impetus for regulating their learning often comes from outside. Performing the EDP improved the participants’ operation of the task analysis process via goal setting and strategic planning since the “ask” step of the EDP enforces to holistic approach to the given problem and limits the scope of the problem that compels to draw a road map meticulously (Watkins et al., 2014). The STEM activity that the participants experienced might force the adoption of goal setting by them since there is a problem of water deficiency that they should overcome. Additionally, strategic planning might be adopted by the participants because designing of the suitable drip irrigation system might enforce them to selection among the possibilities to reach the best solution of problem. This finding is in agreement with Lawanto et al.’s (2013) findings which showed that task interpretation, which means selection of strategies to attain goals and the criteria for self-assessment, is the most frequently used self-regulation process throughout the engineering design.

Another step of the EDP that is “imagine” in which multiple ideas are generated (Moore et al., 2014) also carries a possibility to promote self-regulation at the forethought phase. Data obtained from the think aloud protocol revealed that one of the participants proposed three possible designs as the solution for the problem and data obtained from others indicated alternative materials to construct specific parts of their designs. The present finding seems to be consistent with the description of the strategic planning in which different factors to reach the optimum performance of the skill is determined (Zimmerman, 2000).

Concerning the findings obtained from the think aloud protocol, the self-regulation processes used in the “plan” and “create” steps of the EDP can be associated with the performance phase of the self-regulation model. This finding corroborates the findings of other studies, in which the “plan” and “create” steps of the EDP were described as “formulation, analysis, and reformulation” and correlated with the performance phase (Li et al., 2020; Zheng et al., 2020). Similar to the self-regulation in engineering design models of Li et al. (2020) and Zheng et al. (2020), the formulation and analysis processes correlated with performance phase have practiced as “plan” and “create” by the participants in terms of writing how they transform their design into prototype with details and constructing the prototype in the present study. Moreover, investigation of the data obtained from the STEM task in the think aloud protocol revealed that practicing the “plan” step of the EDP resulted in remarkable application of processes of the performance phase. Among these self-regulation processes, task strategies became prominent. Since participants explained their designs by dividing them into sections, the “plan” step of the EDP might promote the usage of the task strategy which is related to organizing tasks based on the key components (Zimmerman, 2000). On the other hand, it is somewhat surprising that of the self-control processes, only imagery was not adopted as a sub-process by the participants. Although this result differs from some studies that postulate the mutual influence of cognitive strategies and self-regulation (Clercq et al.,2013; Tas et al.,2019), the deficiency of the mental picturizing prototype provides insight into the recessive character of the “create” step of the EDP in the findings of the STEM task in the think aloud protocol.

The statements of the participants that were categorized under the “test & improve” step of the EDP are closely related to the self-reflection phase due to the evaluation of the experience was found as common ground for them. In the STEM activity, the participants evaluated their prototype based on the criteria like number of drips of water per minute and improve it to reach the indicated criteria primarily. The evaluation of the product at the “test & improve” step might arouse self-reflection. The evaluation of product after determining the best solution and performing it in the EDP is similar to determining learning goal, showing performance to reach the goal, and evaluating the attainment of the goal in the phase of self-reflection of self-regulation. This finding corroborates the ideas of Sabag et al. (2014), who suggested that reflection cannot be aroused naturally, irregularity in the design fosters the emergence of it. For this reason, the "test & improve" step of the EDP might stimulate self-regulation in the self-reflection phase.

Overall, how the processes of self-regulation and steps of the EDP are related with each other has explained in the Figure 2.9. Thanks to the model presented in the study it might be executed that cyclical nature of self-regulation show parallelism with the iterative nature of the EDP in the basis of the phases of forethought, performance, and self-reflection with the steps of the engineering design model (English & King, 2015; Moore et al., 2014).

5.2 Conclusion

The purpose of the current study was to understand the role of the engineering design-based instruction on the pre-service chemistry teachers' STEM conceptions and adoption of self-regulation processes. One of the most significant findings to emerge from this study is that STEM descriptions of the pre-service chemistry teachers enhanced after the implementation of the EDP throughout STEM activity. Practicing the STEM activity has the potential to contribute to the pre-service chemistry teachers' STEM definition in the sense of placing "based on real-life" locution that is one of the building blocks of the STEM definition (Sanders, 2009; Moore et al., 2014). Moreover, after practicing the STEM activity, the pre-service chemistry teachers' knowledge about the nature of the integration of the STEM disciplines has progressed beyond the multidisciplinary level which might be associated with the role of engineering as a bridge between the STEM disciplines, as stated by the pre-service chemistry teachers. In addition to the enhancement of STEM descriptions and understanding of the nature of iSTEM, the attitude of the pre-service chemistry teachers toward STEM education has improved in the present study. Although the pre-service teachers have indicated some hesitations related to the implementation of STEM like time limitation, there was predominant consensus about its importance regarding its contribution to problem-solving skills, meaningful learning, enhancing interest, and a qualified workforce. The present study makes a noteworthy contribution to the importance of the application of the STEM activities in the context of the EDP since it has the potential to enhance not only the STEM desciptions of the pre-service chemistry teachers but also the opinions of STEM in a limited period of time.

The second major finding was that the implementation of the EDP provided an environment for the adoption of multiple self-regulation processes. After the implementation of the STEM activity, results showed that different self-regulation processes were used by the pre-service chemistry teachers specific to the steps of engineering design. It was detected that "ask" and "imagine" steps of the EDP tended to promote self-regulation in the forethought phase, "plan" and "create" steps were likely to increase self-regulation in the performance phase, and "test & improve" might make contribution to self-regulation in the self-reflection phase. This study extends our knowledge of the EDP from the viewpoint of self-regulation framework by providing discernment about detailed information about the self-regulation processes attained through the steps of the EDP.

Overall, this study has gone some way towards enhancing our understanding of the STEM education based on the EDP to improve the STEM conceptions of pre-service chemistry teachers. Additionally, addressing self-regulation while working with the STEM problems contributes to existing knowledge of the EDP in terms of promoting cognitive and metacognitive skills of the pre-service chemistry teachers.

5.3 Implications for Practice

The present study offers remarkable information about the engineering design-based instruction in terms of the development of STEM conceptions and adoption of self-regulation processes. Since it presents both theoretical and practical features of STEM, the present study provides implications for teacher educators. The suggestions of the present study for teacher educators are as follows:

When the role of teachers shaping society is considered, education programs should be updated to not fall beyond global innovations. Therefore, teacher education programs should place STEM learning in their curriculum to raise qualified pre-service teachers who are well-equipped with the skills of the 21st century. When the findings of the interviews are considered, it appears that the implementation of the STEM activity improves knowledge of the pre-service chemistry teachers about STEM. Therefore, it can be used in the content of chemistry education programs. However, since the practice of the STEM activities requires large time span, implementation of the STEM activity may be presented as term project after theoretical knowledge about STEM was provided. These results also provide further support for the EDP to enhance the knowledge of iSTEM. Results of the study showed that understanding the nature of STEM improved when the pre-service chemistry teachers dealt with the STEM problem in the context of engineering. Practicing the STEM activity with a well-structured guideline will enhance teachers' knowledge about engineering in STEM as well as iSTEM.

Some of the issues emerging from the findings relate specifically to the implementation of self-regulation processes. When the findings of the think aloud protocol were taken into consideration, it was seen that various self-regulation processes were adopted by the pre-service chemistry teachers after the STEM activity that based on the EDP was implemented. This finding has important implications for developing self-regulation. An increase in the adoption of self-regulation processes by the pre-service chemistry teachers may influence their approach towards the learning process and make them more conscious individuals with regards to shaping the learning process.

5.4 Recommendations for Further Research

Although the results of the present study indicated that the pre-service chemistry teachers' conceptions of STEM and their adoption of self-regulation processes might improve when the STEM activity was implemented through the EDP, still there is abundant room for further progress. Therefore, recommendations are presented for future studies as follows:

In this study, Zimmerman's (2000) cyclical model of self-regulation was adapted to understand the adoption of self-regulation processes. Different models of self-regulation can be used to investigate the implications of self-regulation throughout the EDP.

The implementation of the STEM activity might be performed by K-12 students instead of the pre-service teachers and enhancement of STEM conceptions and level of self-regulation may be traced.

The subject of the STEM activity has taken from the 9^{th} grade chemistry curriculum related to water consumption. In further studies, the subject of the task may be broadened as environmental chemistry and the usage of artificial intelligence might be promoted to find a solution for environmental problems.

In the STEM activity engineering and science were the dominant disciplines. The role of technology and mathematics might be enhanced to increase the level of integration between the disciplines.

Besides the qualitative tools, surveys to measure the STEM knowledge of participants may be used to increase the reliability of data.

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APPENDICES

A. Approval Obtained from Human Subjects Ethics Committee

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
MIDDLE EAST TECHNICAL UNIVERSITY

Konu: Değerlendirme Sonucu

29 KASIM 2023

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Prof. Dr. Esen Uzuntiryaki Kondakçı

Danışmanlığını yürüttüğünüz Elif YILMAZOĞLU'nun ***"Mühendislik Temelli FeTeMM Eğitiminin Öğretmen Adaylarının FeTeMM Bilgisi ve FeTeMM Öğrenimi İçin Öz Düzenlemeleri Üzerindeki Rolü"*** başlıklı araştırmanız İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek 0479-ODTUİAEK-2023 protokol numarası ile onaylanmıştır.

Bilgilerinize saygılarımla sunarım.

Prof. Dr. Ş. Halil TURAN
Başkan

Prof.Dr. İ. Semih AKÇOMAK
Üye

Doç. Dr. Ali Emre Turgut
Üye

Doç. Dr. Şerife SEVİNÇ
Üye

Doç.Dr. Murat Perit ÇAKIR
Üye

Dr. Öğretim Üyesi Süreyya ÖZCAN KABASAKAL
Üye

Dr. Öğretim Üyesi Müge GÜNDÜZ
Üye

B. Interview Protocols

Pre-Interview Questions

Questions Regarding to Prior STEM Knowledge

1. STEM nedir? S, T, E, M harfleri neyi temsil etmektedir?
2. STEM hakkında daha önce eğitim aldınız mı? Eğitim aldıysanız nereden aldınız?
3. Sizce STEM öğrenimi ve öğretimi önemli midir? Neden?
4. STEM içinde yer alan disiplinlerin (fen, teknoloji, mühendislik ve matematik) birbirine entegre edilmesi önemli midir? Eğer önemli ise nasıl entegre edilebilir?
5. Her konu STEM yaklaşımına uygun hale getirilerek anlatılabilir mi? Kimya konularından birini STEM yaklaşımını kullanarak öğretecek olsanız, bu konuyu seçerken nelere dikkat edersiniz? Kısaca bu konuyu STEM yaklaşımını kullanarak nasıl anlatacağınızdan bahsedebilir misiniz?

Questions Regarding to Self-regulation

1. STEM önemli midir, öğrenmeli misiniz? Neden?
2. STEM'i iyi öğreneceğinize inanıyor musunuz? Neden?
3. STEM'i çalışmaya başlayacak olsanız, çalışmaya başlamadan önce nasıl hazırlık yaparsınız?
4. STEM'i nasıl çalışırsınız? Sizin için yeni olan bir konuyu öğrenirken kullandığınız teknik/teknikleriniz var mı?
5. STEM'i öğrenip öğrenemediğinizi nasıl değerlendirirsiniz? Eğer öğrenemediğinizi düşünüyorsanız öğrenmek için nasıl bir yol izlersiniz?
6. STEM'i öğrendiğinize karar verdikten sonra, çalışmanızı nasıl bitirirsiniz?

Post-Interview Questions

Questions Regarding to STEM Knowledge

1. STEM nedir? STEM öğrenimi ve öğretimi önemli midir? Neden?
2. STEM içinde yer alan disiplinlerin (fen, teknoloji, mühendislik ve matematik) birbirine entegre edilmesi önemli midir? Eğer önemli ise nasıl entegre edilebilir?
3. Yapmış olduğunuz STEM aktivitesinde, STEM'in içinde yer alan disiplinlerin nasıl kullanıldığını açıklayabilir misiniz? Bu disiplinlerin entegrasyonu konusunda sizce nasıl bir yaklaşım kullanılmıştır?
4. Gerçekleştirdiğiniz STEM aktivitesindeki tecrübelerinize dayanarak kullanılan mühendislik tasarım sürecinin konunun öğrenilmesindeki rolü hakkındaki görüşleriniz nelerdir?
5. Sizce konunun STEM aktivitesi üzerinden anlatılması öğrenciler için yarar sağlayacak mı? Neden?

C. Think Aloud Protocol

OKULUNUZ İÇİN KAĞIT GERİ DÖNÜŞÜMÜ

Ankara'da Ümitköy bölgesi açılan sınava hazırlık kurslarının sayısının artması nedeniyle kağıt israfı sorunu ile karşı karşıya. Belediye, kağıt atıklarının geri dönüştürülmesiyle ilgileniyor ancak olağandışı bu artış sebebiyle özel bir desteğe ihtiyaçları var. Belediyenin atık yönetim komisyonun baş mühendisi olarak sizden çok ince yapılı ve geri dönüşüm ile üretilmiş kağıt üreten bir süzgeç sistemi tasarlamanızı isteniyor.

Malzemeler

- Çeşitli boyutlarda sineklik teli, tül, ip ve tel
- Raptiye
- Çivi
- Çekiç
- Çeşitli boyutlarda çita ve kontrplak
- Cetvel ve pergel
- Makas ve falçata
- Yapıştırıcı
- Atık kağıtlar

Kriterler

- Üretilen kağıt mümkün olduğu kadar ince olmalıdır.
- Kağıt, kağıt boyunca eşit veya tutarlı kalınlığa sahip olmalıdır.
- Kağıtta delik olmamalıdır.
- Kağıt en az 7 x 13 cm boyutunda olmalıdır.
- 2,5 litre su kullanılmalıdır.

Kısıtlamalar

- Yalnızca elinizde bulunan malzemeleri, araçları ve kağıtları kullanabilirsiniz.

Sorular

1. Süzgeç sisteminizin tasarımına nasıl başlarsınız?
2. Verilen kriterlere uygun olarak sisteminizi nasıl tasarlarsınız?
3. Sisteminizin kriterlere uygunluğunu nasıl test edeceksiniz?
4. Sisteminiz kriterlere uygun değilse nasıl bir yol izleyerek kriterlere uygun hale getireceksiniz?

D. STEM Activity Handout

DRIP IRRIGATION SYSTEM

Freshwater resources, the essence of life, have been facing a global crisis for the last fifty years. The effects of this rapidly growing crisis are manifested in many challenges such as increasing freshwater scarcity, lack of access to adequate clean drinking water and sanitation, deterioration of water quality, fragmentation of water management nationally and globally, reduced financial resource allocation for water development, and threat to world peace and security. The World Water Council (World Water Council) was established to combat all these challenges and raise public awareness based on the principles of a clear evaluation of the world's freshwater resources, the implementation of integrated water resources management and the valuation of water in order to determine water, life and environment vision of world for the next century (Abu-Zeid, 1998).

As mentioned, the scarcity of freshwater resources available worldwide makes their utilization for irrigation inadequate. This situation is exacerbated in regions characterized by a semi-arid climate with little rainfall and high evapotranspiration. Therefore, it is of great importance to improve water use efficiency by using improved irrigation techniques (Robles, Botía and Pérez-Pérez, 2016).

Between the existing irrigation techniques (sprinkling, drip, etc.), drip irrigation slowly applies water where it is most needed in the plant root zone and, unlike other types of irrigation, is 90% efficient as it reduces runoff and evaporation, allowing plants to use the applied water (Drip Irrigation, n.d.).

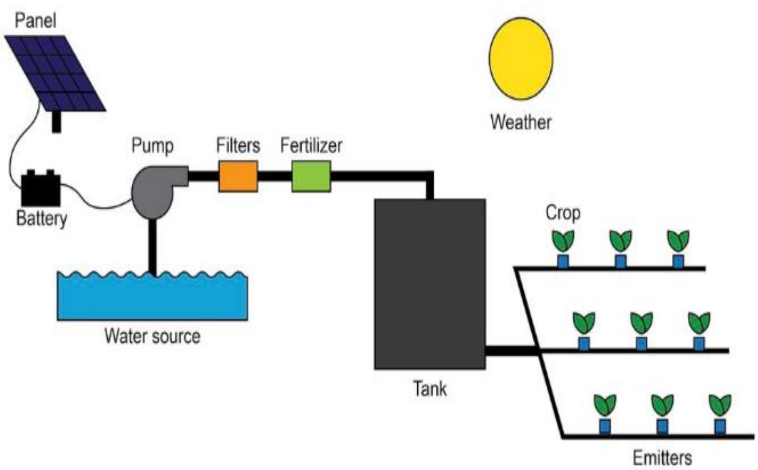

Figure 1: Drip Irrıgatıon System

A drip irrigation system is a system in which irrigation water is filtered and applied as drops on or into the soil surface with or without soluble fertiliser. It delivers water and nutrients to the root of the plant in the right amount and at the right time. Thus, it ensures that a plant receives the water and nutrients that it needs at the right time and helps plants to grow at the optimum level. Thanks to the drip irrigation system; higher yields are obtained by saving water, fertiliser and energy resources (rivulisLMadmin, 2023).

Figure-1 shows a diagram of one of the examples of drip irrigation technique (MIT GEAR Lab., n.d.).

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DESIGNING DRIP IRRIGATION SYSTEM

You are team of engineers who will work in the drip irrigation system that will be designed for the permaculture area planned to be established at University X.

Create a prototype of the system that will optimally meet the conditions.

- Materials:
  Cardboard, paper, ruler, compass, pencil, tape, adhesive, glue, cutters, scissors, nails, pushpins, simple water motor, motor circuit parts, pipe, straw, plastic bottle, sawdust, pebbles, sand, cotton, soil, plant, plastic containers, cardboard cups, pieces of wooden sticks, wire, pliers, syringe

Note: You do not have to use all the materials provided above.

- Criteria:

1- Water should be filtered before irrigation.
2- The planted soil area should not be larger than 1m2.
3- The amount of water used should not exceed 750 mL.
4- All plants should be watered equally.
5- Irrigation speed should be adjusted to be at least one drop per minute.
6- It should be presented in an aesthetically appealing way.

- Constraints:

1- The system to be installed should not harm the living organisms in the soil and should not prevent the cultivation of the soil.

2- The maximum time given for making the prototype is five hours.

- **Please use the following template throughout the design process.**

A. ASK *(Please write down the problem as a real-life question.)*

- Problem:

- Criteria:

- Constraints:

B. IMAGINE (*Please brainstorm and note down the ideas you have reached.*

- Ideas:

- The best idea:

Pros	Cons

C. PLAN (*Please provide a detailed planning of your best idea in stepwise manner and a rough sketch of our design.)*

- Plan:

- Required materials:

D. CREATE (*Please write down formation and construction process of your design step by step.)*

- Prototype:

E. TEST (*Please test your prototype and write down the results.)*

- Test results:

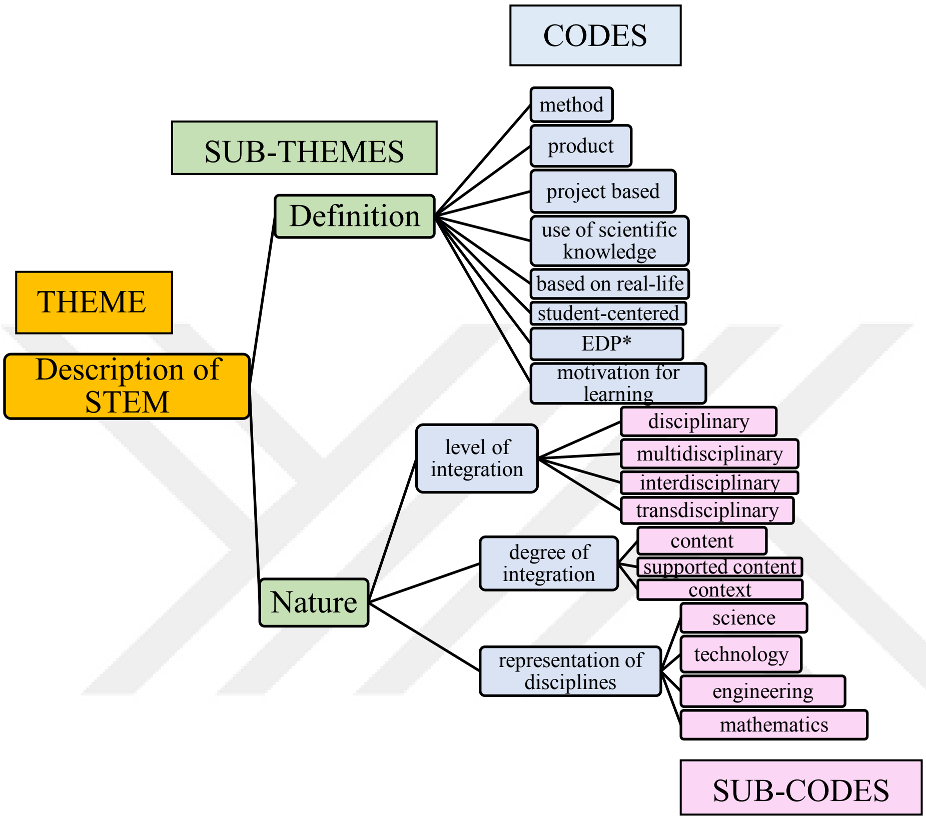
- Things that need to be changed:

F. IMPROVE (Please *specify the iteration process of your design after getting feedback.)*

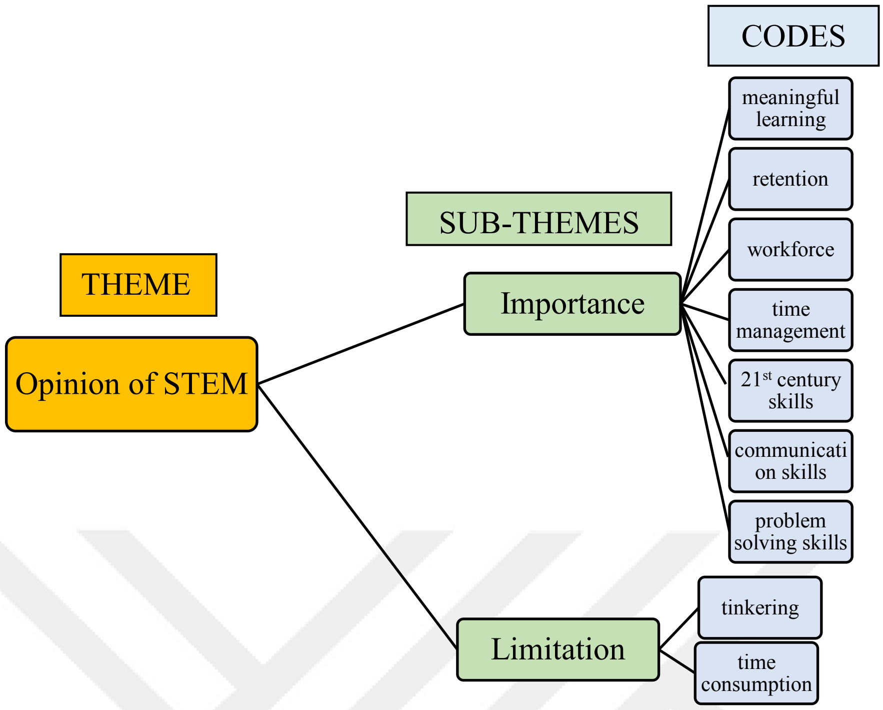
- Modifications:

- Retest:

E. Coding Protocol for the Conceptions of STEM



Note*: EDP refers to engineering design process.


CODES
meaningful learning
retention
SUB-THEMES
workforce
THEME
Importance
time management
Opinion of STEM
21st century skills
communication skills
problem solving skills
tinkering
Limitation
time consumption