




Examination of pre-service chemistry teachers' STEM conceptions through an integrated STEM course

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ABSTRACT Due to international calls for the use of the integrated Science, Technology, Engineering, and Mathematics (STEM) approach to train learners pursuing STEM-related careers and citizens who are competitive problem solvers, teachers' training for the integrated STEM approach is imperative. Given the importance of integrated STEM teacher training, this study aimed to examine how pre-service chemistry teachers' integrated STEM conceptions have been changed through the integrated STEM course. The STEM reflection protocol was administered to 13 pre-service chemistry teachers both at the beginning and at the end of a 13-week-long integrated STEM course. The training included experiencing STEM activities, studying with mentors, and reflecting on own development. The deductive, inductive, and constant comparative data analysis revealed that most of the pre-service chemistry teachers enriched their STEM conceptions in terms of the engineering design process as a context and integration of the disciplines. However, very few participants' STEM conceptions remained the same. Integrated STEM teacher education should include an explicit emphasis on disciplines' integration and engineering design process to enhance pre-service teachers' integrated STEM conceptions.

Keywords: *Integrated STEM education, STEM conceptions, Teacher education*

Kimya öğretmen adaylarının FeTeMM'e yönelik kavramlarındaki değişimin FeTeMM dersi boyunca incelenmesi

ÖZ Bütünleşik fen, teknoloji, mühendislik ve matematik (FeTeMM) yaklaşımının kullanımına yönelik uluslararası ve ulusal çağrılar ışığında, FETEMM iş alanlarını tercih eden ve problem çözebilen bireyleri yetiştirmek için öğretmenlerin eğitilmesi zorunludur. Bütünleşik FeTeMM yaklaşımına yönelik eğitimin öğretmenlerin kavramlarını, alan bilgilerini ve uygulamalarını etkilediğini göz önüne alarak, bu çalışmanın amacı bütünleşik FeTeMM dersi boyunca kimya öğretmen adaylarının bütünleşik FeTeMM kavramlarının nasıl değiştiğini incelemektir. Çalışmada, 13 kimya öğretmen adayına 13 hafta süren bütünleşik FeTeMM dersinin başında ve sonunda FeTeMM'i nasıl kavradıklarına ilişkin bir FeTeMM Zihinsel Model Protokolü uygulanmıştır. Eğitim, bütünleşik FeTeMM eğitiminin ne olduğunun kavranması, FeTeMM aktivitelerinin uygulanması, mentorlar ile beraber çalışma ve öğretmen adaylarının kendi gelişimlerine odaklandıkları yansıtıcı düşünme boyutlarını içermektedir. Tümevarım, tümdengelim ve sürekli karşılaştırmalı analiz yöntemleri ile analiz edilen veriler ışığında, öğretmen adaylarının büyük çoğunluğunun FeTeMM kavramlarının geliştiği, özellikle FeTeMM kavramlarında mühendislik tasarım sürecini ve disiplinler arası ilişkiyi vurguladıkları bulunmuştur. Bu sonuçtan hareketle, bütünleşik FeTeMM öğretmen eğitiminde, öğretmen adaylarının bütünleşik FeTeMM kavramlarının geliştirilmesi için FeTeMM disiplinleri arasındaki ilişkiye ve mühendislik tasarım sürecine açık bir şekilde vurgu yapılmalıdır.

Anahtar Sözcükler:

Bütünleşik FeTeMM eğitimi, FeTeMM kavramları, Öğretmen eğitimi

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INTRODUCTION

The need to equip students with 21st-century skills and direct their career choices to Science, Technology, Engineering, and Mathematics (STEM) fields has promoted the development of integrated STEM education (Moore et al., 2015; Pleasants & Olson, 2019). It provides an ideal environment to develop students' skills such as creative thinking, problem-solving, collaboration, and communication and increase their interest in STEM fields. Therefore, integrated STEM education was developed and integrated into K-12 science education in the United States (US) to ensure continuity in the workforce and support economic growth (Martín-Páez et al., 2019). With the release of the Next Generation Science Standards (NGSS Lead States, 2013), STEM Education took place in the US education system and began to be implemented by many states (Moore et al., 2015). In addition, it has been accepted by many different countries [e.g. Australia (Education Council, 2015), Korea (Ministry of Education, MOE, 2019)] as a new educational approach and has been integrated explicitly into their science standard documents as well (Bartels et al., 2019; Ekiz-Kiran & Aydin-Gunbatar, 2021; Kennedy & Odell, 2014; Shernoff et al., 2017). In some countries, such as Turkey, the STEM approach has not been integrated into the science standard documents with all its components explicitly (Elmas & Gül, 2020). However, there has been a huge interest in integrated STEM education, both from teachers and students (Akaygün & Aslan-Tutak, 2016). Some issues have been arisen in implementing integrated STEM education as a result of the intense interest in such a new perspective on education. One of the most important issues that needed consideration in all countries is the teachers' training (Akgunduz et al., 2015; Shernoff et al., 2017; Timms et al., 2018).

Due to the widespread use of integrated STEM education, the necessity to train teachers about STEM education becomes important to have students gain the targeted skills. Integrated STEM teaching may include the teaching of more than one discipline, or involve one or more teachers working together, in this respect, it is different from the teaching of any discipline alone (Roehrig et al., 2012). Therefore, teachers' content knowledge and their understanding of integrating STEM disciplines are important components for the quality and improvement of integrated STEM education (Zhan et al., 2020). In order to establish the relationship between STEM disciplines, teachers' knowledge and understanding of integrated STEM should be developed (Ring et al., 2017). However, the efforts on teacher training for integrated STEM education are not sufficient (Rinke et al., 2016). To increase the quality of integrated STEM education, first of all, what teachers think about integrated STEM and how they reflect their integrated STEM conceptions should be identified (Ring et al., 2017). As future teachers, training pre-service teachers about STEM education is as important as training in-service teachers. Identifying integrated STEM conceptions of pre-service teachers is the first step for contributing to the design of the teacher education programs tailored to the pre-service teachers' needs, as conceptions of teachers are not stable and subject to development (Radloff & Guzey, 2016). This situation is valid for chemistry teacher education and could be applied to pre-service chemistry teachers. Hence, in this study, we aimed to identify pre-service chemistry teachers' STEM conceptions, how they reflected them in their drawings and explanations, and if there was any change at the end of an integrated STEM course.

Theoretical Framework

How integrated STEM education is defined and implemented?

The integrated STEM approach does not have a common definition in the literature and has been defined in different ways (Martín-Páez et al., 2019). For instance, Moore et al. (2014) described integrated STEM education as an attempt to incorporate any or more of the four fields of science, technology, engineering, and mathematics into a single class, unit, or a lesson focused on the relationship between topics and real-world issues. From a wider view, Johnson (2013) acknowledged integrated STEM education as a teaching approach. According to this approach, science and mathematics teaching are

combined “with scientific research, technological and engineering design, mathematical analysis, and 21st-century interdisciplinary themes and skills” (p. 367). Although STEM stands for acronyms for science, technology, engineering, and mathematics, integrated STEM education does not always include all these disciplines (Stohlmann et al., 2012). Integrated STEM education, according to Kelley and Knowles (2016), should include two or more STEM domains, whereas Sanders (2009) describes it as techniques that investigate teaching and learning within/between any two or more STEM disciplines, as well as between a STEM discipline and one or more other school disciplines. Although definitions of integrated STEM education have changed, Moore et al. (2014) suggested a framework for STEM integration in the class with the most common six principles of integrated STEM education. According to the framework, integrated STEM curricula should include a motivating and engaging context, engineering design challenges of relevant technologies, learning from failure and redesign process, mathematics and/or science content, student-centered teaching approaches, and teamwork and communication. Rather than defining integrated STEM education, Bybee (2013) provided different STEM perspectives in the literature. Among them, Bybee (2013) listed perspectives that did not reflect integration as expected [e.g., ‘STEM equals Science (or Mathematics)’, STEM means both Science and Mathematics], the ones that emphasized the incorporation of disciplines (e.g. ‘STEM Means Science and Incorporates Technology, Engineering, or Math’, ‘STEM Means Combining Two or Three Disciplines’), and also the views highlighting the integration of disciplines (e.g., ‘STEM Means a Transdisciplinary Course or Program’).

When implementing integrated STEM education, it is possible to focus on all content areas or to highlight one and use the others as a context for learning disciplinary content (Moore et al., 2014). As a result, STEM integration can be implemented in two ways; content integration and context integration (Moore et al., 2020; Roehrig et al., 2012). Content integration includes combining learning goals for more than one STEM discipline into a single activity. For instance, Roehrig et al. (2012) created a STEM professional development program with a fully integrated STEM context, including a wind turbine and heat transfer activity. Participating teachers practice engineering design by considering the elements that influence blade design and efficiency using wind turbine kits, as well as the physics underlying different blade designs. The activity also entails the implementation of the mathematics that underpins the gear system to properly construct a practical wind turbine. Thus, in this activity, content integration is needed to be used to teach content from different disciplines while emphasizing how all of these disciplines are required to address the issue.

Different from content integration, context integration concentrates on the content of a single STEM discipline and uses other STEM disciplines as a context to meet the learning goals. In implementing integrated STEM education, engineering design creates an ideal real-world context for students to engage in authentic problems (Moore et al., 2014; Roehrig et al., 2012). Therefore, while integrated STEM activities are implemented in science lessons, most of the time, the engineering discipline is used as a context to solve real-world problems based on scientific and mathematical knowledge (Brophy et al., 2008; Guzey et al., 2017). Wieselmann et al. (2020) designed a STEM learning environment for elementary school students where they collaborated to design an electromagnetic arm for a game. Students engaged in an engineering design challenge and applied the electromagnetism-related science knowledge that they had learned throughout the unit. In this way, researchers provide a framework for teaching science and improving students' science competency through engineering design.

Research on teachers' integrated STEM conceptions

In order to achieve the targeted points with the STEM reform, the starting point should be to determine the conceptions of the teachers about the STEM approach (Ring et al., 2017). Teachers are implementers of the STEM approach, which requires their solid conceptualization of the approach. It is vital because their conceptualization of the STEM approach reflects into their implementation (Ring-Whalen et al., 2018). With this in mind, researchers have focused on identifying teachers' STEM conceptions, the changes in teachers' STEM conceptions throughout teacher training, and the other possible ways to capture teachers' STEM conceptions. In this part of the study, research on teachers' (i.e., both pre- and

in-service teachers) STEM conceptions would be presented.

In the related literature, some of the studies examined teachers' existing STEM conceptions. For example, Radloff and Guzey (2016) dig into 159 pre-service science teachers' STEM conceptions in a cross-sectional survey study. Based on Bybee's (2013) STEM categorizations, among the visualizations drawn by the participants, the most common one was interconnected STEM conception (n=54). Although most of the drawings included integrated and overlapping disciplines, n=28 participants' conception was siloed. Radloff and Guzey (2016) claimed that the existence of siloed conception of STEM is most probably related to the educational system in which each discipline is taught in different classes in an isolated way. Similarly, Güler et al. (2017) examined 49 pre-service science teachers' STEM conceptions in a survey study. Results showed that the most common STEM conceptions were interconnected visualization (n=13), nested visualization (n=10), and transdisciplinary visualization (n=6). Moreover, almost 20% of the visualizations could not be categorized by Güler et al. (2017) due to vague drawings or explanations. The authors argued that pre-service teachers' STEM conceptions showed a large spectrum. Despite the large spectrum in conceptions specified with the visualizations, the explanation behind the drawings was limited, which was that the STEM disciplines are connected. In conclusion, pre-service teachers' STEM conceptions reflected very few aspects of the STEM approach (e.g., integrated nature) and missed other important ones (e.g., engineering design, teamwork, and communication). Likewise, in-service teachers had similar superficial STEM conceptions before STEM training (e.g., Öztay & Aydın-Günbatır, 2019; Ring et al., 2017), which would be summarized in the following paragraph.

Based on the aforementioned studies' results reporting teachers' inadequate STEM conceptions with limited explanations, researchers also paid attention to develop teachers' STEM conceptions throughout teacher training. Ring et al. (2017) focused on how in-service teachers' integrated STEM conceptions evolve through a 3-week STEM training. The comparison of pre-, mid, and post-data collected by the use of the STEM reflection protocol (i.e., including a drawing and explanation of the drawing) showed the changes in teachers' way of STEM conceptualization. The first set of data included simple STEM models and limited details about the participants' STEM conceptions. In the second data set, the participants' conceptions moved to more 'integrated disciplines', 'STEM+', and 'teamwork' models (i.e., the details and definitions of those models would be presented in the Data Analysis part of this study). The third iteration of the protocol revealed that teachers' drawings had more details. Overall, thirty teachers changed their conceptions from the first to the third iteration of the STEM reflection protocol, whereas only three had the same conceptions from the beginning to the end. Likewise, Öztay and Aydın-Günbatır (2019) examined 24 in-service chemistry teachers' STEM conceptions before and after a week-long STEM training by the use of STEM Reflection Protocol developed by Ring et al. (2017) in Turkey. Results showed that in pre-conceptions, very few teachers included engineering design (n=1) and daily-life problems (n=1). Moreover, drawings and explanations had very limited details regarding their pre-STEM conceptions. At the end of the training, participants' conceptions included engineering design (n=7), teamwork (n=2), communication (n=1), and STEM+ (n=5). In addition to in-service teachers, Akaygun and Aslan-Tutak (2016) examined how pre-service chemistry and mathematics teachers' STEM conceptions developed through a four-week Collaboratively Learning to Teach STEM (CLT-STEM) module. Different from the other studies regarding including participants with different STEM backgrounds made the study unique. Moreover, the researchers modeled the cooperation necessary among the STEM fields, which has been emphasized in the literature (Bartels et al., 2019). Although to some extent the integration of STEM disciplines was detected in the participants' first STEM posters, owing to the integrated nature of the CLT module, pre-service chemistry and mathematics teachers drew more integrated STEM models with real-world problems and collaboration emphasis in the final posters. Results also revealed that even the participants whose STEM conceptions did not develop showed a deeper understanding of the purpose of the STEM approach. Finally, Aydın-Günbatır et al. (2018) aimed to focus on how pre-service chemistry teachers' STEM conceptions develop over an integrated STEM course. In the beginning, the participants mostly had 'STEM as an acronym' model in their minds. Very few of them mentioned the interdisciplinary nature of STEM and the real-world problem-solving aspects in their models. After the integrated STEM course including

integrated STEM activities based on daily-life challenges, engineering and design process, and integration of STEM disciplines, the models included more interdisciplinary nature, engaging daily life problem and challenges, inquiry and problem-based learning and creativity. To conclude, based on the results revealed, it can be argued that STEM training including theoretical aspects introducing integrated STEM approach and engineering, STEM activities with engineering emphasis, 21st-century skills, and STEM+ (i.e., both for pre- and in-service teachers) helped the participants change their limited STEM conceptions with the detailed ones. Moreover, collaboration and teamwork experience through training are necessary since the existence of small groups is a sine qua non of integrated STEM implementation (Wieselmann et al., 2020).

Finally, researchers have quested to find better ways to capture teachers' STEM conceptions. The reason behind that seek is related to the difficulty in the categorization of some participants' STEM conceptions (i.e., both drawings and explanations). For example, Güler et al. (2017) reported that due to vague drawings or explanations almost 20% of the visualizations could not be categorized. To solve the problem, Dare et al. (2019) developed photo-elicitation interviews (PEI), through which the participants were asked to rank eight STEM models (i.e., models formed in light of the related literature) and put them in order from least to most desirable ones. Results revealed that teachers mostly selected the models that emphasize daily-life problems and integration of STEM disciplines. The least desirable ones include 'STEM as an acronym' and 'STEM as separate disciplines' models. To end with, in addition to STEM Reflection Protocol, using at-hand STEM models that have been mostly drawn and mentioned by teachers in previous studies may be a good solution in order not to lose data with vague drawings and/ or explanations.

To conclude, based on the review of the related literature, teachers' STEM conceptualizations are limited. However, owing to STEM training with STEM activities emphasizing engineering design process, teamwork, 21-st century skills (e.g., communication), integration of different STEM disciplines informed teachers about the true nature of the STEM approach and its implementation. Regarding methodologies, in addition to drawings and interviews, recent PEI seems to simplify researchers' work to capture and categorize teachers' STEM conceptions in their minds.

Significance of the Study

With the recent call for implementing integrated STEM education by NGSS (NGSS Lead States, 2013), the first step that should be taken is to focus on teachers' integrated STEM conceptions that would reflect on their implementation (Ring et al., 2017). To move STEM beyond a slogan (Bybee, 2010), it is time to realize that teachers' understanding of integrated STEM education in theory and practice is not adequate (Dare et al., 2019). Furthermore, a systematic review on STEM education conducted by Margot and Kettler (2019) reported the inadequacy of teacher training (i.e., both for pre-and in-service teachers) to help them develop an understanding of integrated STEM education. Although in-service teacher training has been paid attention to, pre-service teacher education has been neglected (Radloff & Guzey, 2016). Assisting pre-service teachers in constructing solid STEM conceptualization would provide a smooth transition to teaching STEM in class (Faikhamta, 2020; Radloff & Guzey, 2016; 2017). Therefore, pre-service teachers should be introduced to integrated STEM conception and provided with opportunities to experience integrated STEM lessons during teacher education programs (Bartels et al., 2019). To address the issues raised, this study aimed to shed light on how the participant pre-service chemistry teachers' conceptions of integrated STEM change over an elective semester-long integrated STEM course. Different from the previous studies (e.g., Dare et al., 2019; Öztay & Aydın-Günbatır, 2019; Ring et al., 2017; Ring-Whalen et al., 2018), this study was conducted with pre-service chemistry teachers. Although some studies examined pre-service teachers' STEM conceptions (e.g., Aydın-Günbatır et al., 2018; Güler et al., 2017), this study is different regarding the engineering emphasis made (see detail in Table 1) through 13-week long training (e.g., compared to Güler et al., 2017 and Radloff & Guzey, 2016, which did not provide any training to the participants). The explicit emphasis on 'introducing engineering, and engineering design process' in week 1 and 'Introducing instructional strategies used for design teaching' in week 11 were made (see Table 1). The reason behind the

engineering and design emphasis was both the authors' experience received from previous training and the STEM conception literature that has revealed the pre-service teachers' limited experience or no experience in engineering knowledge (e.g., Vossen et al., 2020). In addition to engineering emphasis, this recent training offered was unique regarding its cyclic nature that includes learning theoretical aspects of integrated STEM education, experiencing STEM activities, studying with experienced mentors, and reflecting on the experience provided through the training. With those in mind, the results of the study including a rich and distinctive training cycle have the potential to inform the related literature about pre-service teachers' initial STEM conceptualizations, and how training informed and developed that initial conceptualization, which is valuable for training incoming STEM educators.

Based on the points summarized above, the following research questions directed this study:

How do pre-service chemistry teachers conceptualize integrated STEM education, both in their drawings and explanations?

How do pre-service chemistry teachers' integrated STEM conceptions change both in their drawings and explanations during the training?

METHOD

Research Design

This study is qualitative. Specifically, it is a case study (Miles & Huberman, 1994) that digs into the changes in pre-service teachers' integrated STEM conceptions through a 13-week-long integrated STEM course. This study provides comprehensive information about the participants' initial and final integrated STEM conceptions, and how the training provided helped the participants develop integrated STEM conceptions.

The Participants

An elective Integrated STEM Education course was offered to junior pre-service teachers enrolled in the Chemistry Education division. 13 pre-service chemistry teachers (10 females, 3 males) selected the course in the 2019-2020 Fall semester. The participants were 20-21 years old. Before the integrated STEM course, they took chemistry content courses (e.g., General Chemistry, Analytical Chemistry), pedagogy courses (e.g., Introduction to Education, Program Development and Teaching). Through the semester the study was conducted, the participants took content courses (e.g., organic and physical chemistry), and pedagogy courses (e.g., classroom management), and chemistry teaching methods course (i.e., integrated STEM approach was not covered in the method course). The participants did not take any integrated STEM courses during the study other than the elective Integrated STEM Education course. Moreover, they do not have any experience in presenting their conceptions with drawing. However, they had experience in writing their conceptions and ideas (i.e., the first author taught Teaching Chemistry Methods Course in the previous semester, through which she asked the pre-service chemistry teachers to write reflection papers on their development, learning, difficulties, etc. through the semester.)

The participants were informed about the purpose of the study. They participated in the study voluntarily and knew that they could withdraw at any time of the study. The necessary ethical permission was taken from the Institutional Review Board of Yuzuncu Yil University (i.e., the document number was 85157263-663.05-E.18615). Moreover, pseudonym names were used to address the anonymity of the participants. The course grading did not include the data collected for this study.

Design of the Training

The study was conducted during a 13-week elective integrated STEM course offered in the chemistry teacher education program. Since the authors have a background in chemistry education, chemistry is the science discipline emphasized during the course and the dominant STEM discipline as well. In other words, the course design was based on context integration (Moore et al., 2014). Throughout the course, pre-service chemistry teachers engaged in practices to integrate their chemistry knowledge with mathematical and technological knowledge and/or practices in an engineering design process. The training included an iterative process of four main types of practices: learning, experiencing, studying with mentors, and reflecting on experiences as given in Table 1 [also you can see Aydin-Gunbatar et al. (2020) for more details].

Table 1.

Details of the Training Provided throughout the Integrated STEM Course

| Week | Details of the Training |
|------|------------------------------------------------------------------------------|
| 1 | Introducing integrated STEM, engineering, and engineering design process |
| 2 | Inquiry-based STEM activity: Preventing apples from browning |
| 3 | Argumentation-based STEM activity: Design your thermos |
| 4 | Analysis of a good example of STEM lesson plan on airbag design with mentors |
| 5 | Project-based STEM activity: Making bouncy polymer |
| 6 | Argumentation-based STEM activity: Making a rocket |
| 7 | Analysis of a poor STEM lesson plan on making toothpaste with mentors |
| 8 | Inquiry-based STEM activity: Designing a fire extinguisher |
| 9 | Inquiry-based STEM activity: Design a voltaic cell with the highest voltage |
| 10 | Adapting a cookbook science activity into a STEM activity with mentors |
| 11 | Introducing instructional strategies used for design teaching |
| 12 | Developing a new STEM lesson plan in groups with mentors |
| 13 | Pre-service teachers reflect on the contribution of the course |

Throughout the training, pre-service teachers participated in six integrated STEM activities which are designed to solve authentic problems. The STEM activities were designed either as an inquiry or an argumentation activity. For instance, in the second week of the training, pre-service teachers participated in an inquiry-based integrated STEM activity to prevent an apple from browning. In the third week, they participated in an argumentation-based activity to design a thermos to keep their drinks hot. During the activities, the participants were expected to respond to the questions given in the design logs, including the steps of the engineering design process suggested by Wheeler, Whitworth and Gonczi (2014) (an example of a design log was given in Appendix-A). Moreover, in these activities, participants were supposed to use mathematical knowledge/practices for calculating, collecting data, interpreting graphs...etc., or technological knowledge/practices to collect data, present their designs, search the web, etc. During the activities, pre-service teachers worked in groups and the group members were changed in each activity that each participant has the chance to communicate with different peers throughout the training. Also, they were encouraged to use their creativity in aesthetic designs wherever possible (e.g., in thermos design). At the end of the activities, each group presented their designs either as oral or poster presentations to the whole class and they discussed the strength and weaknesses of the designs and shared the difficulties they encountered during the design process.

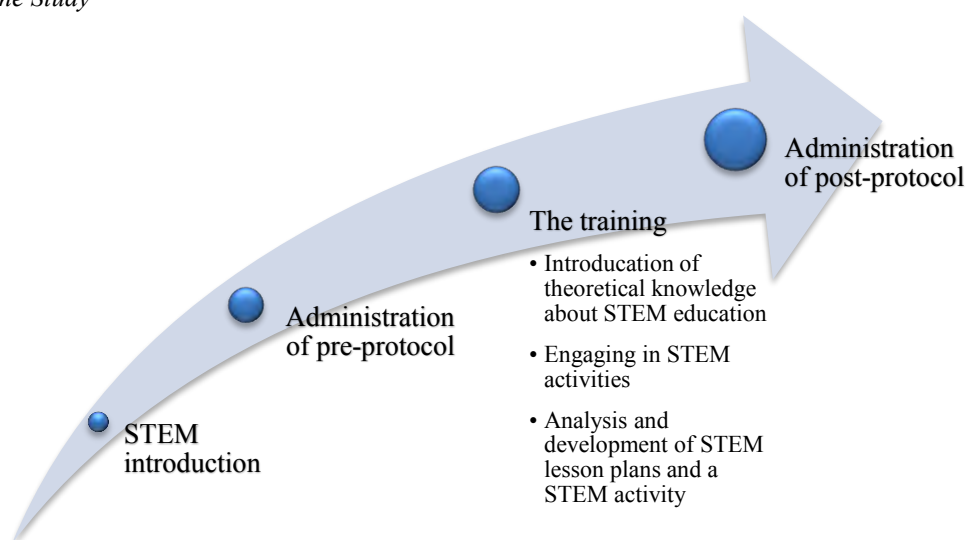
In addition to engaging with integrated STEM activities, in some of the weeks, the instructor provided detailed information to pre-service teachers about the subject being learned. For instance, as it is given in Table 1, in the first week, the instructor introduced integrated STEM, engineering, and engineering design processes to pre-service teachers. She presented what STEM and engineering are, the need for integrated STEM education, and how different disciplines could be integrated into each other in integrated STEM education. In addition to that, in three weeks (i.e., 4th, 7th, and 10th weeks), the pre-service teachers worked with mentors who had Ph.D. in chemistry education and working on integrated STEM education. Three mentors helped participants understand the good practices to integrate STEM disciplines and implement quality STEM education. For instance, pre-service teachers worked in groups to analyze good and weak STEM lesson plans with mentors (i.e., one mentor worked with 4-5

participants in each group). While analyzing the lesson plans, mentors drew attention to the actions that led to strong and weak plans and helped participants comprehend those actions. They discussed how to improve a weak plan, how to integrate different STEM disciplines, and what the effective parts of a strong plan were.

Data Collection

In the current study, the STEM Reflection Protocol given in Appendix-B was used to collect the data. The protocol was developed by Ring et al. (2017) to find out teachers' STEM conceptions with both drawing and explanation. In this study, two questions of the protocol were used and participants were asked to *i)* draw their model of STEM integration and *ii)* explain their models. The protocol was administered twice, in the second week and at the end of the training. In this way, we could examine the change (if there was any) in participants' integrated STEM conceptions including drawing and explanation. The timeline of the study was given in Figure 1.

Figure 1.
Timeline of the Study



Before the training, pre-service teachers had never been enrolled in an integrated STEM course and were not familiar with integrated STEM education. In the first week of the course, the instructor asked pre-service teachers whether they were familiar with integrated STEM education. All participants confirmed that they were not familiar with the concept and none of the participants answered the instructor's questions about integrated STEM education confidently and correctly. Therefore, for being explicit about what we meant by integrated STEM education and to create a shared language with the pre-service teachers, the instructor introduced the integrated STEM, engineering, and engineering design process to pre-service teachers in the first week. Then, in the second week, before engaging in the STEM activities, the STEM Reflection Protocol was administered to the pre-service teachers for the first time. The second administration of the protocol was at the end of the training.

Data Analysis

We analyzed pre-service chemistry teachers' integrated STEM conceptions through deductive and inductive coding (Miles & Huberman, 1994). The deductive coding was conducted through the use of existing codes (i.e., created by Ring et al., 2017). The inductive coding was conducted by adding new codes depending on the data of the study. Through the data analysis, pre-service teachers' conceptions reflected on STEM protocol were the primary data source. The written explanations of the models were used as a secondary source to categorize the STEM conceptions.

The data analysis process was conducted in two rounds. First, two of the researchers coded half of the data (i.e., both from pre-and post-data) independently utilizing the codes provided by Ring et al. (2017) and Bybee (2013). Then, these researchers came together, compared and contrasted their codes. Some differences in coding were identified. To solve them, they discussed until they reached a consensus. In this meeting, the draft code list was also revised due to the discussions held. Moreover, new codes were emerged, namely creativity and transdisciplinary. At the end of this round, nine codes were used to analyze the data as given in Table 2. In the second round of the coding, two of the researchers coded the rest of the data again utilizing the revised code list independently. Then, they came together and compared the coding. The indication of reliability, inter-coder agreement was calculated using Miles and Huberman's (1994) formula as 0.82 in the first round of coding and 0.94 in the second round of coding. Miles and Huberman (1994) set a 0.80 value as sufficient for the agreement. Therefore, inter-coder agreement values can be accepted as sufficient.

Table 2.
Codes about STEM Education and Their Descriptions

| Codes | Description of the codes |
|-----------------------------------------|-------------------------------------------------------------------------------------------------------------------------|
| STEM as separate disciplines | Participants could not integrate STEM disciplines; they view STEM disciplines as separate. |
| STEM as integrated disciplines | Participants integrate between/among any two or more of the STEM disciplines. |
| Transdisciplinary | Participants view STEM as a whole subject. |
| Engineering design process as a context | Participants design a product or process to solve a real-world problem using an iterative process of engineering design |
| Real-world problem solving as context | Participants integrate STEM disciplines to solve a real-world problem |
| Teamwork | Participants mention that during STEM education learners work as a team member or in a group. |
| Communication | Participants mention that STEM leads learners to communicate to solve real-world problems. |
| Creativity | Participants mention that STEM helps learners to improve their creativity. |
| Vague or no answer | Not compatible with STEM education |

One participant's STEM conception was coded utilizing more than one code if necessary. For example, in some cases, participant's drawing and explanation include both integration of STEM disciplines and teamwork. After the coding was completed, through a constant comparative way, the researchers compared and contrasted pre-service teachers' initial and final STEM conceptions to investigate how the conceptions changed through the integrated STEM course (Corbin & Strauss, 2014).

For the trustworthiness of the study, confirmability was ensured by providing detailed explanations regarding the design of the training, data collection tool, and data analysis process to provide more realistic and richer information for the readers. Also, the validity of the study was enhanced by triangulating data with drawings and explanations to examine participants' STEM conceptions. We achieved credibility of the results by member-checking. For this purpose, we provided an opportunity for participants to comment on the findings and explain whether the findings of the study were compatible with their experiences. Furthermore, we explained all procedures in this study such as the data analysis process, codes and their descriptions in detail, and the design of the training throughout the semester to be applicable in a new setting to enhance transferability of the findings of the study (Creswell, 2009).

RESULTS

In this part, first, the categorizations of the participants' STEM conceptions at the beginning and at the end of the training were presented. Then, the changes in pre-service teachers' STEM conceptions were provided. The distribution of pre-service teachers' STEM conceptions for both pre and post

administration of the protocol was presented in Table 3.

Table 3.

The Summary of Pre-Service Teachers' Initial and Final STEM Conceptions

| Conceptions' Name | Pre-service teacher' initial STEM conceptions in the pre-administration | Pre-service teacher' final STEM conceptions in the post-administration |
|---------------------------------------------|-------------------------------------------------------------------------|------------------------------------------------------------------------|
| STEM as separate disciplines | Emilia, Ella, Carlos | Ella, Carlos |
| STEM as integrated disciplines | Sam, Natalie, Valeria, Carol, Nicole, Sandra, Emma | Sam, Natalie, Valeria, Isabel, Emma, Nicole, Sandra, Alena |
| Transdisciplinary | - | Carol, Emilia |
| The engineering design process as a context | - | Emma, Nicole, Natalie, Sandra, Valeria, Isabel, Alena |
| Real-world problem solving as context | - | Emilia |
| Teamwork | Natalie | Nicole, Natalie, Alena |
| Communication | - | Alena |
| Creativity | - | Sandra |
| Vague or no answer | Fred, Isabel, Alena | Fred |

At the beginning of the course, the distribution of the pre-service teachers' conceptions regarding the integrated STEM education included four types of connections out of nine. While the most frequently emerged model was integrated disciplines (n= 7), the least frequently represented STEM model was teamwork (n=1). This result indicated that pre-service teachers were aware that STEM education including different disciplines namely science, technology, mathematics and engineering, and there should be a connection among them. However, they could not mention the connections among any two or more disciplines of STEM accurately. In addition, most of them noted that they had difficulty both in drawing and explaining their conceptions. Hence, their initial STEM conceptions were superficial. For example, Nicole's initial conception included the integration of science and technology (Figure 2). She drew only computer and lab materials to indicate how technology is utilized to improve science. Similarly, Valeria's model represented that the researcher utilized STEM disciplines to conduct research (Figure 3). She emphasized science, technology, and mathematics disciplines in her drawing. As it was seen in Figure 2 and Figure 3, initial conceptions of those pre-service teachers did not emphasize the interdisciplinary nature of integrated STEM education explicitly.

Figure 2.

Nicole's Initial STEM Conception with Her Description

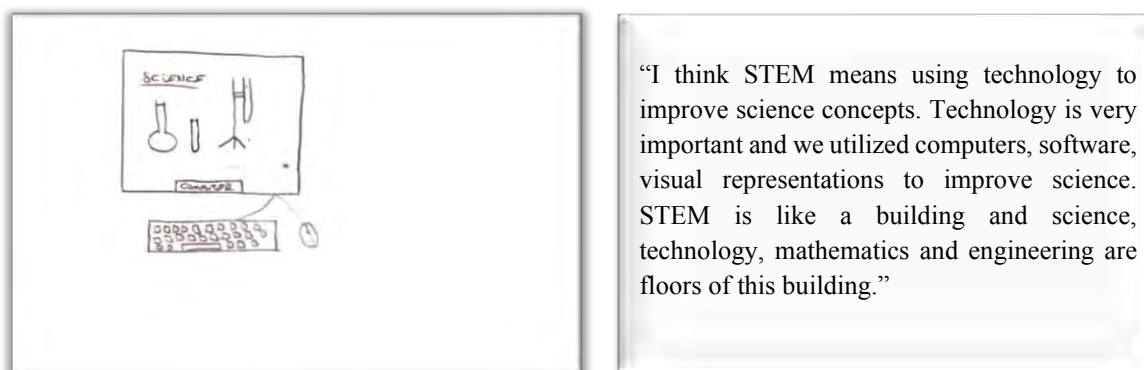
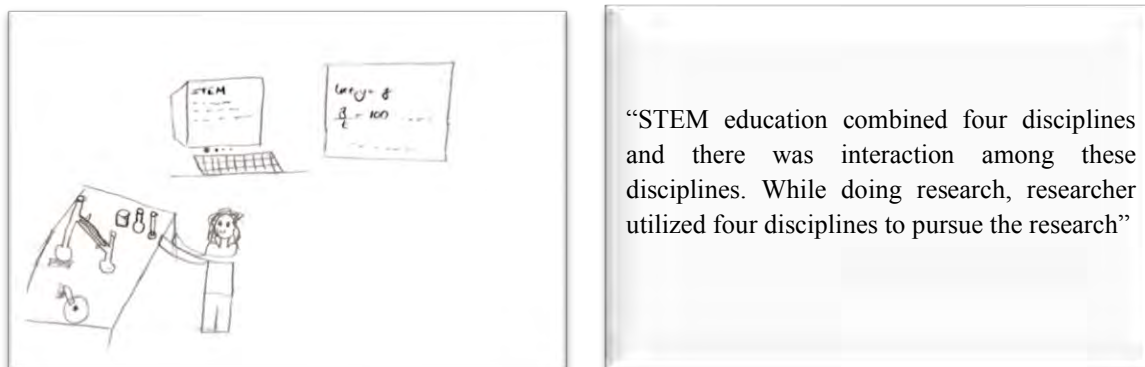
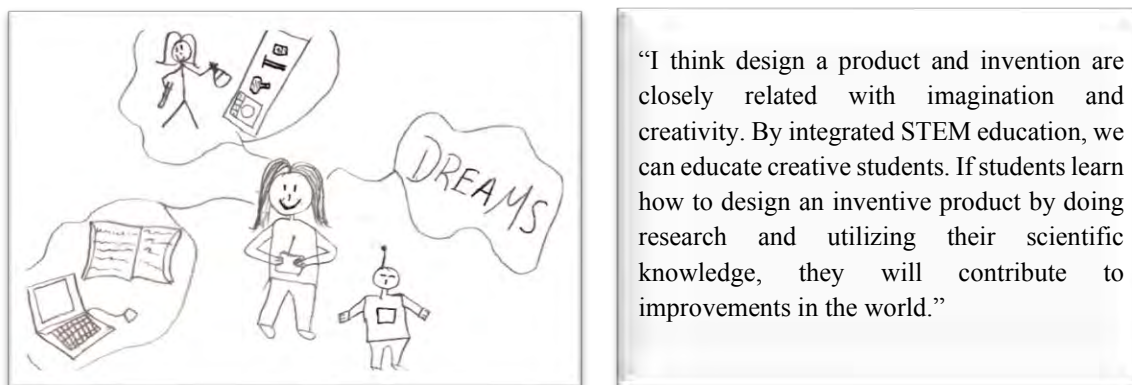


Figure 3.
Valeria's Initial STEM Conception with Her Description



At the end of the course, most of the pre-service teachers' conceptions of integrated STEM education were improved and included more details. Analysis of the data collected at the end of the course indicated that pre-service teachers had a variety of conceptions regarding integrated STEM education. Furthermore, the later conceptions were more complex and included more details compared to the initial ones. In the final, the number of integrated STEM conceptions coded as integrated disciplines increased from seven to eight. Moreover, teamwork code increased from one to three. In addition to the increase in the numbers, pre-service teachers' conceptions regarding integrated disciplines were more comprehensive at the end of the course when compared to the beginning. For instance, Figure 4 represents Sandra's final integrated STEM conception emphasizing the interdisciplinary nature of STEM supported by creativity code.

Figure 4.
Sandra's Final STEM Conception



Furthermore, at the end of the semester, pre-service teachers mentioned transdisciplinary (n=2), engineering design process as context (n=7), real-world problem solving as context (n=1), and 21st-century skills as communication (n=1) and creativity (n=1) on their STEM conceptions at the end of the course while those codes were not presented in any of the pre-service teachers' initial conception. For example, in Figure 5, Isabel drew an engineer and mentioned that integrated STEM education should include design process through which science, technology, and mathematics are integrated.

Figure 5.
Isabel's Final STEM Conception



“Integrated STEM education incorporates more than one discipline. STEM education leads students to design a product using materials they came across in their daily life so they gain perspective to solve real-world problems.”

At the end of the course, the participants also emphasized 21st-century skills like communication and teamwork (Figure 6).

Figure 6.
Alena's Final STEM Conception

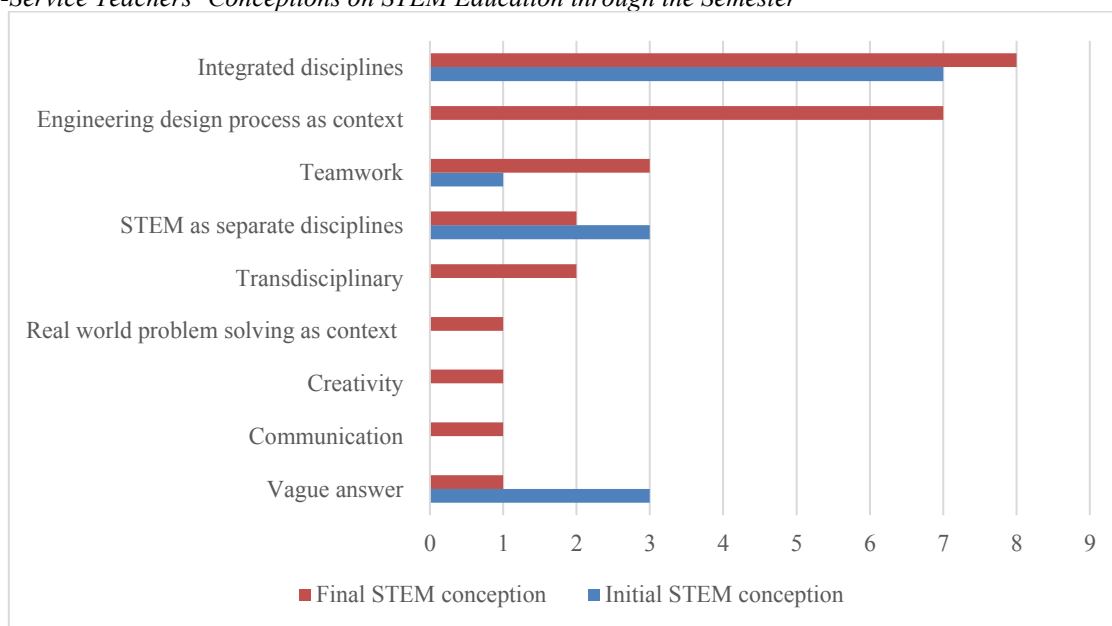


1. Students do brainstorming and talk about their ideas. Also, they do research.
2. They made calculations based on their research.
3. They design a product.”

Changes in Pre-Service Teachers' Conceptions on Integrated STEM Education

When the participants' initial and final integrated STEM conceptions were compared and contrasted, some improvements were observed (Figure 7). Through the course, only four pre-service teachers' integrated STEM conceptions (i.e., Sam, Fred, Ella, and Carlos) remained constant. In addition, in a few pre-service teachers' conception, there was an inconsistency between drawing and explanations regarding how they conceptualize integrated STEM education.

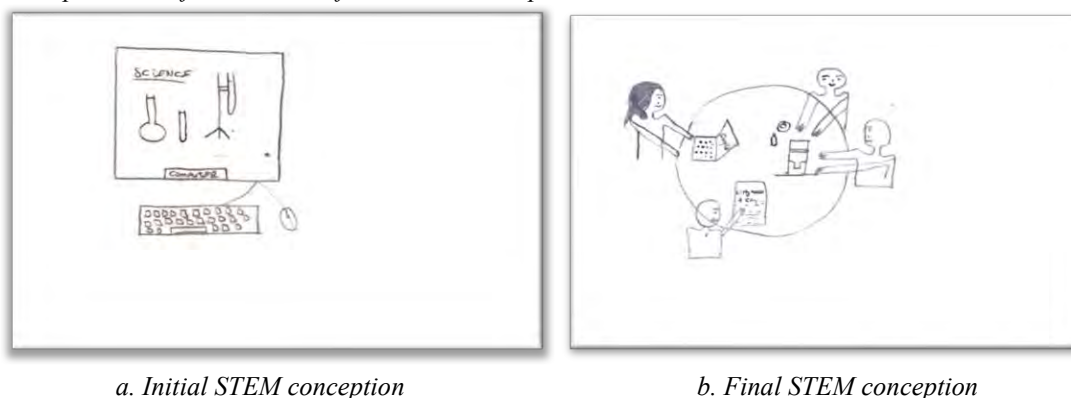
Figure 7.
Pre-Service Teachers' Conceptions on STEM Education through the Semester



Most of the pre-service teachers indicated remarkable improvement in terms of defining integrated STEM education as engineering design process as context (from $n=0$ to $n=7$). The number of participants who emphasized the interdisciplinary nature of integrated STEM was also increased from seven to eight. Moreover, 21st-century skills as teamwork, communication, and creativity codes were also increased through the course. For example, as provided in Figure 8, Nicole improved her integrated STEM conception from integrated disciplines to the engineering design process as context supported by teamwork. Her initial STEM conception included just integration between science, and technology, which was coded as integrated disciplines. On the other hand, in her final STEM conception, she emphasized design a product through integrating STEM disciplines with a group working. She explained her final conception as:

In my drawing, students work in groups and they integrate all STEM disciplines, science, mathematics, technology and engineering to design a product. During STEM education, students do research with a group, make calculations, and use their content knowledge to make a design.

Figure 8.
Nicole's improvement from initial to final STEM conception.



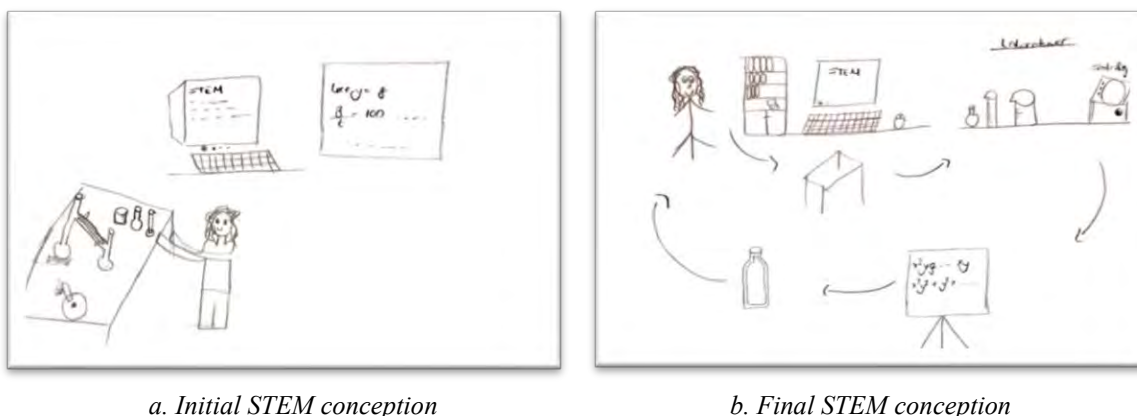
Likewise, Nicole's improvement from initial to final STEM conception, Valeria's STEM conceptions were also improved as shown in Figure 9. Her initial STEM conception was coded as integrated disciplines due to utilizing science, technology, and mathematics disciplines to solve a problem. Through the course, there was a shift in her integrated STEM conception. The arrows in the final

drawing indicated an iterative engineering design process to solve the problem. She explained her drawing as follows:

First, I will research utilizing the internet, books, etc. about the topic. Then, I will do experiments and observations based on this knowledge. I will calculate the mathematical part of the topic. Then, I will design a product. During this process, in some steps, I may need to revise my research or retest the design until I reach the desired results.

Although her explanation was not very detailed, Valeria tried to explain the iterative nature of engineering design processes, which was evident that she gained a more sophisticated integrated STEM conception through the integrated STEM course.

Figure 9.
Valeria's STEM Conceptions' Shift

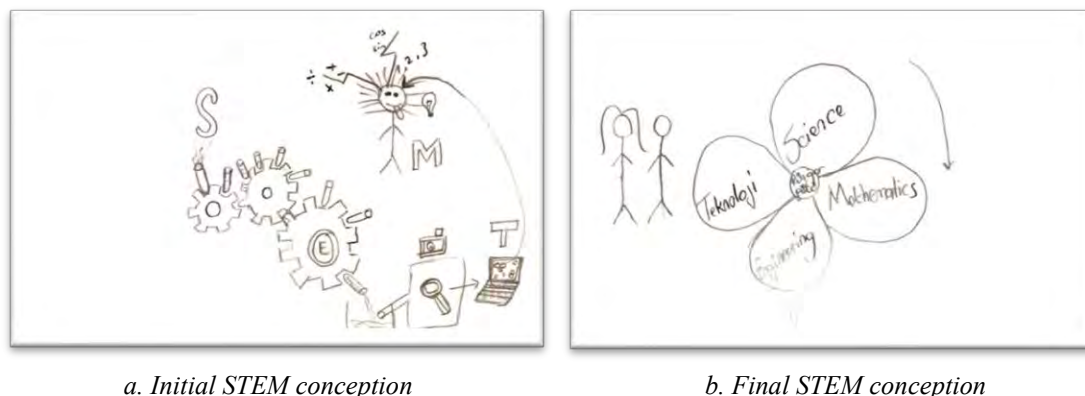


In addition to improvements, the researchers also faced inconsistencies between the participants' drawings and explanations (Figure 10). Carol's initial STEM conception was coded as integrated disciplines due to emphasizing the interaction among STEM disciplines. Based on Carol's final drawing, her final STEM conception could be coded as STEM as separate disciplines. However, she explained her drawing pertained to her STEM conceptions as following:

We can associate STEM education with a paper windmill. Every leaf of the windmill is a different color but when it turns we can see just one color. I think STEM is also composed of different disciplines but during STEM education all these disciplines combined and turn into a body.

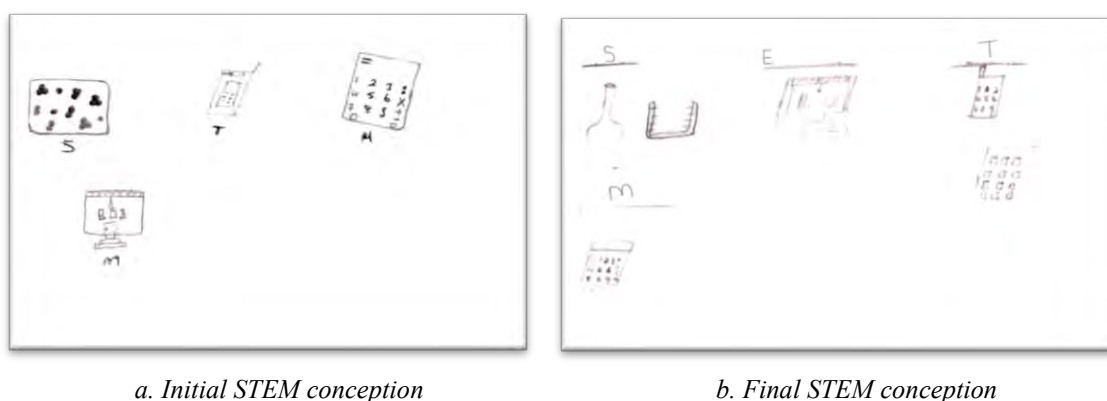
Hence, her final STEM conception was coded as transdisciplinary because she did not focus on any of the STEM disciplines, she conceptualized STEM as a whole.

Figure 10.
Carol's STEM Conceptions' Shift



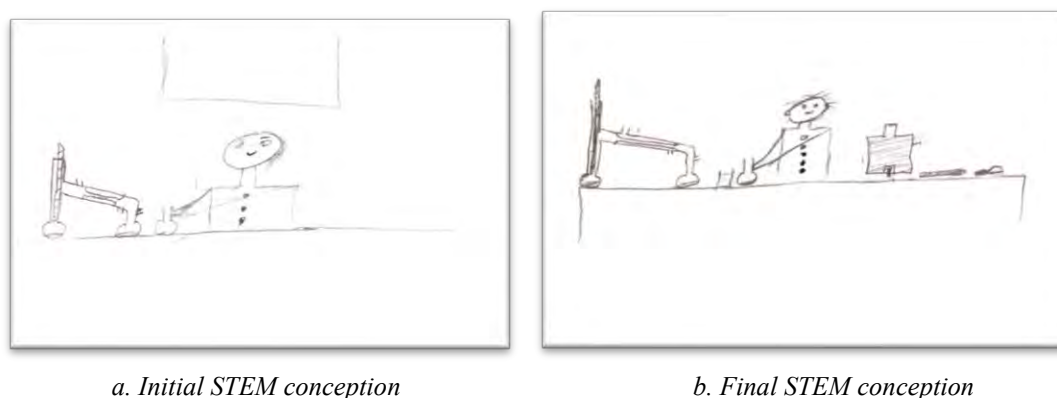
In addition to developments, throughout the 13-week integrated STEM course, there was a decrease in models coded as STEM as separate disciplines and vague answers. Two out of three participants who identified STEM education as separate disciplines in the initial and final administration of the STEM reflection protocol were the same participants (i.e., Ella and Carlos). In Figure 11, Ella did not change her STEM conceptions through the course. Her initial and final conceptions were coded as STEM as separate disciplines. She could not integrate the disciplines. She also explained her final STEM conception as “in my opinion, Science refers to laboratory materials, the periodic table, etc. Mathematics refers to calculation and calculator. Technology refers to tablet, phone, computer, etc. and Engineering refers to the construction and designing a product” which supported her drawing including separate STEM disciplines.

Figure 11.
Ella's Initial and Final STEM Conceptions



Finally, at the beginning of the course, two pre-service teachers (Isabel and Alena) did not take initial STEM conception so they were coded as no answer. In the end, their conceptions were coded as engineering design process as context (see Figure 5 and Figure 6) at the end of the course. On the other hand, Fred's model was coded as vague both on pre-and post-STEM protocol. He drew a man making an experiment but he did not relate it to STEM education (Figure 12). Hence, his model was coded as a vague answer.

Figure 12.
Fred's Initial and Final STEM Conceptions



DISCUSSION AND IMPLICATIONS

Given the importance of investigating pre-service teachers' STEM conceptions, in this study, we aimed to focus on how the pre-service teachers' STEM conceptions evolved through a 13-week long integrated

STEM course. In the light of the results, most pre-service chemistry teachers enriched their conceptions regarding the engineering design process as a context, 21st-century skills (e.g., communication, teamwork, and creativity), and integration of the disciplines. However, very few participants' conceptions remained the same. Yet another point that deserves attention was the inconsistency between the participants' drawings and explanations for the integrated STEM conception. The discussion part would be organized based on those three points.

First, most of the participants' integrated STEM conceptions and the complexity of their explanations regarding the engineering design process as a context, communication, teamwork, creativity, and integrated disciplines increased at the end of the training. The engineering design process as context emerged as the most increased conception, although none of the participants indicated it as a STEM conception at the beginning. Before the training started, the participants were informed about integrated STEM education, engineering, and engineering design processes. Moreover, they engaged in six different integrated STEM activities prepared within the engineering design model suggested by Wheeler et al. (2014) and the activities were guided by a design log that included the steps of the engineering design process. The modelling of integrated STEM activities provided through the course allowed participants to develop their conceptions regarding integrated STEM (Bartels et al., 2019). Moore et al. (2014) emphasized that integrating separate disciplines was challenging. However, "engineering is a natural connector for integrated STEM disciplines" and engineering design challenges provided a suitable context for the integration (Moore et al., 2014, p. 37). Moreover, effective integrated STEM education is provided by making "connections among the STEM disciplines more transparent" (English, 2016, p.7). Therefore, we argued that explicit emphasis and continuous participation in integrated STEM practices and engineering design processes most probably lead participants to develop their conceptions of integrated STEM (e.g., engineering design process as context). Considering the benefits of integrating engineering design into classroom practice, the development of 21st-century skills was inevitable (Dare et al., 2019). Besides, 21st-century skills such as teamwork, communication, and creativity were the increased conceptions of the participants in this study. As Ring et al. (2017) claimed, the possible reason for this result could be that the participants of the current study realized the necessity and advantages of integrating these skills into the activities through the course. As it was known, working in a small group is one of the essential features of the integrated STEM approach (Wieselmann et al., 2020). In the training provided, all integrated STEM activities were designed to allow participants to work as a team, communicate with each other, and support creative design. Therefore, the participants had a chance to practice these skills and integrated them into their STEM conceptions. The design of the course provided pre-service teachers' awareness and a clear understanding of the conceptions of integrated STEM education. To summarize, explicit emphasis on STEM disciplines' integration and engineering design, and the iterative use of the engineering design process supported the development of pre-service teachers' integrated STEM conceptions and should be included in the courses and training to enhance their integrated STEM conceptions.

Second, although the intended increase (i.e., with more sophisticated drawings and details) was reached in most of the participants' STEM conceptions at the end of the integrated STEM course, a few participants' STEM conceptions remained the same. Despite the explicit emphasis on the integration of different STEM disciplines, surprisingly two pre-service teachers conceptualized STEM as separate disciplines both at the beginning and at the end of the course. That could be related to the time necessary for change in those two participants' STEM conceptions. Until this course, they took separate courses for each STEM discipline (i.e., except engineering; no engineering course was offered either in K-12 or in the college). On the contrary, the integrated STEM training provided in the course took only 13 weeks. Hence, the time duration might not be enough for them to change their conception that highlighted separate STEM disciplines. Akaygun and Aslan-Tutak (2016) reported similar results with no change or decrease in the pre-service teachers' integrated STEM conceptions. The researchers revealed that the groups' STEM conceptions with a decrease included a focus shift from STEM definition to the purpose of STEM training from initial to final drawings. Regarding the point discussed, Ring-Whalen et al. (2018) argued that the amount of experience that teachers have had in the training is an important source determining their confidence about STEM conceptions. Moreover, Ring-Whalen et al. (2018)

emphasized that although all participants received the same training, they conceptualized their model, which indicates that each participant might take different meanings. Therefore, it should be necessary to accept that time and experience necessary for the conceptual change that may be different from one to another participant. In light of the point raised, teacher education programs should offer more integrated STEM education and interdisciplinary courses for pre-service teachers through the program (Horvath et al., 2018) to help teachers understand what integration means and train them to implement integrated STEM curricula (Faikhamta, 2020).

A final point deserving attention was that the inconsistencies between the drawing and the explanation of the integrated STEM conception. In addition to inconsistencies, the participants also had difficulty in drawing their conception in this study. Hence, they tended to provide more and detailed explanations for their conception. A similar situation was reported by Ring et al. (2017) and revealed that in many cases, teachers did not draw a figure for their conception. Rather, they only provided explanations. To address the problem, photo-elicitation interview (PEI) can be used. During the PEIs, the participants are shown digitally created STEM models based on the literature and researchers' experience. Dare et al. (2019) revealed that PEIs provided richer and deeper data regarding the participant teachers' STEM conceptions. Due to interviews and the at-hand models, teachers had more chance to comment on the models and how those similar or different from their conceptions. In the light of Dare et al. (2019) and their creative idea of using PEI, in future studies richer and more detailed data would be collected for identifying and/or examining changes in teachers' STEM conceptions.

The limitations of the study were; (i) the small number of participants to the training, (ii) the integrated STEM training lasted 13 weeks, (iii) the data collected for determining and examining the changes in the STEM conceptions included only drawings and explanations, (iv) the STEM training provided was an example of a context integration rather than content integration one. In light of limitations, the literature review and the results presented, in the future, studies conducted with more participants, by the use of different data sources (e.g., lesson plans, observations of teachers' STEM implementation), throughout longer integrated STEM training have more potential to provide a richer and deeper understanding of pre-service teachers' STEM conceptions and the development in the STEM conceptions through the training provided. In Turkey's context, due to the limited number of studies focusing on pre-and in-service science/chemistry/mathematics/technology teachers' STEM conceptions and how those conceptions direct their STEM implementation, more studies would enlighten the literature. Moreover, the results of the studies would provide useful information about the next steps taken for STEM teacher training.

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APPENDICES

Appendix A: An Example of a Design Log

Brainstorming

Which materials can you use in a thermos? Record any thoughts that may be helpful.

Research

What scientific knowledge are you interested in knowing about designing a thermos?

What materials do you think are best for a thermos? Why?

What sources can help with your research?

What do you need to know to solve this problem? Write questions you want to investigate.

At the end of your research, if you have learnt anything useful, write them down with a different color pen.

Design:

Design your thermos and write the materials used. Receive feedback from your instructor.

Write your claim on why you think your design will work.

Claim-1:

Construction and Testing:

Construct your thermos and test it. Record the data and evaluate its effectiveness against the criteria outlined before design process started.

Explain how your data collected supports your argument.

Redesign:

How can you make your design better? Try at least one suggestion to make the design better. Then return to the design step and write down what you have changed in a different color pencil.

Re-design your thermos based on your original design and revisions.

Data:

Outline the final version of your design. What was your argument in your final design?

Claim-2:

How final data supported argument-2? Explain.

Evaluation:

Evaluate your thermos design based on the criteria outlined at the beginning.

Compare and contrast the initial and final versions of the design. Consider how you have improved.

Appendix B: STEM Reflection Protocol

How would you depict your model of STEM Integration?

Describe your model in words below:

TÜRKÇE GENİŞLETİLMİŞ ÖZET

Son yıllarda tüm dünyada yaygın şekilde çalışılan ve birçok ülkenin eğitim sistemlerinde değişikliklere neden olan bütünleşik Fen, Teknoloji, Mühendislik ve Matematik (FeTeMM) yaklaşımı ülkemizde de öğretim programlarına entegre edilmiştir. İlgili alan yazında daha önce yapılan araştırmalarda öğretmenlerin ve öğretmen adaylarının zihinlerindeki FeTeMM kavramının istenen düzeyden uzak olabileceği rapor edilmiştir. Ayrıca, bu yapıların verilen kaliteli ve uygulamalı eğitimler ile değişip zenginleşebileceği de vurgulanmıştır (Ring vd., 2017). Özellikle hizmet öncesi öğretmen adaylarının FeTeMM kavramlarının çok çalışılmadığı Radloff ve Guzey (2016) tarafından belirtilmiştir. Ancak öğretmen adaylarının mesleğe başlamadan önce bu eğitimleri almaları ve FeTeMM kavramını doğru şekilde yapılandırması, ilerideki FeTeMM uygulamalarına olumlu yansıtacak ve sınıflarında daha rahat uygulamalar yapabilmelerine katkıda bulunacaktır (Radloff & Guzey, 2016). Alan yazındaki bu eksiklikten yola çıkarak, nitel bir durum çalışması olan bu araştırmada 13 haftalık FeTeMM dersi kapsamında verilen FeTeMM eğitiminin öncesi ve sonrasında 13 öğretmen adayının FeTeMM kavramları ve bu kavramlardaki değişimi incelenmiştir. Çalışma 2019-2020 güz döneminde gerçekleştirilmiştir. Verilen FeTeMM eğitimi; teorik FeTeMM, mühendislik ve mühendislik tasarım süreci eğitimi, altı farklı bütünleşik FeTeMM etkinliğine katılma ve sonrasında bu etkinliğin kazandırdıkları ile ilgili yansıtıcı rapor yazma, deneyimli üç kez mentörler ile farklı FeTeMM ders planlarını inceleme, analiz etme ve yeni bir FeTeMM ders planı hazırlama olmak üzere farklı ve alan yazın tarafından kullanılması tavsiye edilen uygulamaları kapsamaktadır.

Belirlenen amaç doğrultusunda Ring vd. (2017) tarafından geliştirilen ve yazarlar tarafından Türkçe'ye çevrilen FeTeMM'e ilişkin Zihinsel Model Protokolü kullanılmıştır. Bu protokol FeTeMM nedir tanıtımı kısaca yapıldıktan sonra dönem başında ve 13 haftalık eğitim sonrasında öğretmen adaylarına iki kez uygulanmıştır. Bu protokole öncelikle katılımcılardan zihinlerinde canlanan FeTeMM'e dair bir şekil çizimleri ve daha sonra da bu şekli yazılı olarak açıklamaları istenmektedir. Veri analizi sırasında alan yazında ortaya konmuş olan (Bybee, 2013; Ring vd., 2017 tarafından sunulanlar) ve veri setini ışığında yeni olarak yazarlar tarafından ortaya konulmuş kodlar kullanılarak katılımcıların eğitim öncesi ve eğitim sonrası FeTeMM kavramları belirlenmiş ve değişimler kategorize edilmiştir. Başka bir deyişle veri analizinde hem tündengelimli hem tümevarımlı hem de sürekli karşılaştırmalı analiz yöntemleri kullanılmıştır. Verilerin kodlaması iki turda gerçekleştirilmiştir. İlk turda eğitim öncesi ve sonrası verilerin yarısı iki araştırmacı tarafından bağımsız olarak kodlanmış ve kodlamalar karşılaştırılmıştır. Bu tur için kodlayıcılar arası tutarlık Miles ve Huberman (1994) formülü kullanılarak .82 olarak elde edilmiştir. Tutarlılıkların ve veri setinden yeni elde edilen temanın tartışılması sonrasında kod listesi yenilenmiş, kodlar daha detaylı açıklanmış olarak ikinci turda yine iki araştırmacı tarafından verilerin kalan yarısı kodlanmıştır. Kodlamaların karşılaştırılması ile bu tur için kodlayıcılar arası tutarlık değeri .94 olarak elde edilmiştir.

Bütünleşik FeTeMM eğitimi öncesinde üç katılımcı 'FeTeMM farklı disiplinlerden oluşur' şeklinde düşünürken yedi katılımcı 'disiplinler arası ilişki' vurgusu yapmıştır. Yine eğitim öncesinde sadece bir katılımcı 'ekip çalışması' vurgusu yapmıştır. Üç öğretmen adayının çizimi ve anlatımı ise anlaşılabilir/belirsiz olarak kategorize edilmiştir. Bütünleşik FeTeMM eğitimi öncesi FeTeMM kavramlarına genel olarak bakılacak olursa eğitim öncesinde basit ve az detay içeren çizimler ve anlatımlar elde edilmiştir. Yukarıda detayları verilen ve dönem boyu süren eğitimler sonrasında ise çizimler ve anlatımlar zenginleşmiş, daha önce vurgulanmayan noktalar eklenmiş ve FeTeMM yaklaşımı özelliklerini daha çok içeren çizim ve açıklamalar elde edilmiştir. Örneğin, daha önce değinilmeyen ve 21. yüzyıl becerileri arasında yer alan 'yaratıcılık' ve 'iletişim' temaları çizim ve açıklamalarda yer almaktadır. Ayrıca, eğitim öncesi sadece bir katılımcının değindiği 'grup çalışması'na dönem sonunda üç kişi tarafından değinilmiştir. Eğitim öncesi sadece disiplinler arası ilişkiye vurgu yapılırken (n=7) eğitim sonunda buna ek olarak (n=8) 'disiplinler üstü' (*İngilizcesi transdisciplinary*) vurgusu da iki katılımcı tarafından yapılmıştır. Yine ders öncesi 'Mühendislik tasarım süreci bağlamı' ve 'Günlük hayat problem bağlamı' temaları hiç görülmezken sırasıyla son uygulamada n=7 ve n=1

katılımcı tarafından deęinilmiştir. Bu gelişim ve istenen deęişimlere ek olarak, verilen eğitim sonrasında bir katılımcının çizimi ve anlatımı ise anlaşılma/belirsiz olarak kategorize edilirken iki katılımcı da 'FeTeMM farklı disiplinlerden oluşur' kategorisinde kalıp bir deęişim ve gelişim göstermemiştir.

Alan yazında, öğretmenlerin bütünleşik FeTeMM kavramlarının verilen eğitimlerinden etkilendięi ve dinamik bir yapıya sahip olduęunun altı çizilmiştir (Dare vd., 2019; Ring vd., 2017). Bu çalışmada katılımcıların büyük çoğunluęunda hedeflenen gelişime ve deęişime ulaşılmıştır. Bu deęişimde; FeTeMM dersinin (i) altı farklı FeTeMM etkinlięine (örneğin, termos tasarımı, en yüksek voltaja sahip pil tasarımı, yangın söndürücü tasarımı, vb.) birebir katılma şansı vermesi; ve (ii) etkinliklerin hepsinde etkinlięi mühendislik tasarım süreci temelinde yönlendiren çalışma kâğıdının kullanılması (İngilizcesi *design log*, Appendix-B'de sunulmuştur); (iii) dönem boyunca üç kez deneyimli mentörler ile birlikte bütünleşik FeTeMM ders planı inceleme ve ders planı tasarlama şansı verilmesi; ve (iv) teorik bütünleşik FeTeMM ve mühendislik tasarım süreci tanıtımlarının etkili olduęu düşünülmektedir. Gelişim gösteremeyen katılımcılar açısından durum incelendiğinde ise yaklaşık on beş senelik öğrenim hayatları boyunca FeTeMM disiplinlerine ait dersleri ayrı ve bağlantısız şekilde almış olmalarının etkisi olduęu ve bazı kişiler için bu deęişimin bir dönemden daha uzun bir süre gerektirdięi argümanı akla gelmektedir. Benzer şekilde bulgulara ulaşan Ring-Whalen vd. (2018) bütünleşik FeTeMM tecrübesinin ve alınmış olan eğitiminin süresinin bu deęişime etki ettięinin altını çizmektedir. Ayrıca, aynı şekilde eğitim alınmış olsa da bu eğitimin herkes için aynı anlama gelmedięini ve farklı şekillerde algılamalara yol açtıęını vurgulamışlardır.

Çalışma bulguları ve alan yazın ışığında öğretmen adayı ve öğretmenlerin FeTeMM kavramları incelenmeli, verilen eğitimlerin bu kavrama etkileri incelenmeli ve bu kavramların öğretmenlerin sınıf içi uygulamalarına nasıl yansıdığı çalışılmalıdır. Bazı katılımcılar için hedeflenen gelişimin gerçekleşmedięini ortaya koyan bu çalışmadan çıkacak önemli bir öneri de hizmet öncesi öğretmen eğitimi programlarında daha fazla sayıda ve daha uzun sürelerde bütünleşik FeTeMM ve disiplinler arası yaklaşımların tanıtıldığı ve uygulama şansının verildięi dersler sunulmalıdır. Benzer öneri aynı şekilde hizmet-içi öğretmen eğitimleri için de geçerli olup uzun süreli ve farklı deneyimler sunan eğitimler ile deęişim ve gelişim sağlanmalıdır.