

## PRE-SERVICE TEACHERS' DESIGN OF STEAM LEARNING UNITS: STEAM CAPABILITIES' ANALYSIS

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### Abstract

The understanding of what constitutes effective practice in STEM education and how to support it is still developing, as it is a brand-new field. The present research describes the design capabilities of pre-service elementary school teachers, when they design collaboratively STEM activities. These designing experiences occurred in a context of a PD program called “Introduction to STEM education”. During the STEM PD program, the pre-service teachers worked in six groups. Each group included three pre-service teachers who worked together throughout the PD program. Three written STEM units of three groups were chosen to be analyzed. In analyzing the STEM units, we referred to the STEM capabilities which consists of three components: STEM knowledge, skills and ways of thinking. The findings show different possibilities that STEM education can afford for task design. In terms of the integration of disciplines, the three analyzed units included activities in which, mostly, at least two disciplines were dominant. In terms of STEM skills, the designed units targeted mainly the individual learning skill instead of collaborative skills, which emphasize the need to pay special emphasis to this issue. Finally, in terms of STEM ways of thinking, analytical and evidence-based ways of thinking prevailed in the three units. The previous findings point at the importance of supporting pre-service teachers in designing STEM activities for implementation in their classrooms.

**Keywords** – STEM education, Activity design, STEM capabilities, Pre-service teachers, Elementary school.

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## 1. Introduction

STEM (science, technology, engineering and math) education is attracting lately the attention of researchers (Çalış, 2020; Kartika, Susanti & Indriyanti, 2021; Kilty, Burrows, Welsh, Kilty, McBride & Bergmaier, 2021; Yllana-Prieto, Jeong & González-Gómez, 2021). This is because STEM education follows the multidisciplinary and integrative approaches, so it can serve more than one discipline at the same time. It also can show the connection between the disciplines, which motivates the student to learn

them. One important issue of this field is the task design issue, where little research has been done on this issue. The present research attempts to shed light on the STEM task design issue by considering three learning units that the participating preservice teachers designed during a PD (Professional development) program that targeted STEM education. In the current research, we consider the design of STEM tasks based on the framework of Harris (2012), where this framework consists of three capabilities: STEM knowledge, STEM skills and STEM ways of thinking.

## 2. Literature Review

Increasing global attention has been paid to STEM, STEAM (the A stands for Art), STREM (the R stands for Robotics), and STREAM (the R stands for Reading) education due to the changing demands of real life and the changing economy in general (ElNagdi & Roehrig, 2020). STEM education aims to provide students with a successful progression from school, university, to the world of work. It also aims to instill a deeper understanding of the global economy so that they can be competitive on the labor market of the future (Guyotte, Sochacka, Costantino, Walther & Kellam, 2014). There are three inclusive STEM education goals according to the National Research Council (2013), namely (a) increasing the number of STEM innovators and professionals, (b) strengthening the STEM-related labor force, and (c) improving STEM literacy among citizens. So, the need for STEM programs and for preparing STEM educators is clear. Especially, when STEM education programs proved their effectiveness on developing students' cognitive, affective, and psychomotor abilities (Firdaus & Rahayu, 2019), as well as on student attitudes toward STEM in general, and toward STEM careers in particular (Guzey, Harwell & Moore, 2014).

According to Catterall (2017), the acronym "STEM" was suggested by the Colwell the 1990s, but three alterations of the term were offered: STEAM (STEM with art), STREM (STEM with robotics) and STREAM (STEM with reading and art). STEM/STEAM/STREM/STREAM education is receiving increasing attention around the world. However, there is considerable uncertainty in how it is defined as well as the course activities and outcomes of this education (Lamberg & Trzynadlowski, 2015). So, various definitions and models were promoted. Siekmann and Korbel (2016) defined STEM as teaching the STEM topics either through a traditional and a discipline-specific approach or through an integrative approach. Differently, Brown, Brown, Reardon and Merrill (2011) defined STEM mentioning one feature, which is the use of an integrated approach, i.e. the feature of combining disciplines rather than teaching them separately. The definition of STEM education by Brown et al. (2011) highlights STEM as a standards-based, meta-discipline-based approach to teaching at the school level where all teachers, especially those in the STEM fields, emphasize an integrated approach to teaching addressed in a fluid, dynamic manner.

The National Science Teachers Association (Eberle, 2010) defined STEM education emphasizing the use of "real-world applications". They say that in STEM education, students develop competencies and skills in four disciplines, where science and math are woven together with engineering and technology in a sequence that builds on itself and can be applied in real-life settings.

McMullin and Reeve (2014) say that even though the government and local school districts are working to implement STEM education, teachers are the deciding factor. Therefore, if we want quality STEM education, it is necessary to understand teachers' and pre-service teachers' perceptions. It was reported that though teachers recognize the importance of STEM education for the talent development of students, they have ill-defined perceptions of STEM education (Lamberg & Trzynadlowski, 2015). Margot and Kettler (2019) argue that it is crucial to discover what teachers believe are the challenges and barriers that impede developing STEM education in classrooms (Paolucci & Wessels, 2017). Other researchers, as Shernoff, Sinha, Bressler and Ginsburg (2017) mentioned specific challenges that teachers encounter while educating STEM, including: planning and implementation time, preparation of pre-service teachers, school organization, evaluation, and access to educational resources.

Meeting the previous challenges, teachers feel that what would support them in their integrating of STEM education are collaboration with other teachers, well-prepared curriculum, school support, experiences

and professional development (Margot & Kettler, 2019). At the same time, in-service and pre-service teachers who had previous experience in teaching with STEM or had professional development in STEM, reported high level of interests, attitudes and skills related to STEM education (Chen, Huang & Wu, 2021). So, it seems that teachers' prior views and experiences influence their STEM teaching.

Therefore, to address the current and future challenges of our world, we need teachers capable of effectively teaching STEM topics and preparing the future workforce (McClure, Guernsey, Clements, Bales, Nichols, Kendall-Taylor et al., 2017); this involves providing professional development programs for STEM education for the in-service teachers and preparing the preservice teachers.

Preparing curriculum materials for STEM education is currently challenging teachers (Guzey et al., 2014). It is recommended by Robertson, Nivens and Lange (2020) that math teachers and pre-service teachers be involved in planning and executing STEM activities as a part of their preparation for teaching STEM, as was done in this research. This provides them with opportunities for professional development, as well as being vital for improving integrated STEM teaching and learning (Guzey, Moore & Harwell, 2016).

The previous argument applies to STEAM, STREM and STREAM education where all of them include STEM, but the later education includes another domain or domains that enrich the learning activities and connects between scientific and humanistic education. Rodrigo (2019) claims that STEM and STREAM not only support learning critical thinking and creativity, but also inspire empathy in learners, encouraging them to use their skills and knowledge for the greater good. Badmus and Omosewo (2020) say that as a result of the introduction of Arts, a paradigm shift occurred in which the conscious application of skill and creative imagination in the production of aesthetic objects, especially in innovation and design, became a new order in STEM. In addition, the robotics in STREM strengthens the problem-solving aspect of the STEM activity and a specific technology notions related to programming (Cesaretti, Storti, Mazzieri, Screpanti, Paesani, Principi & Scaradozzi, 2017).

## 2.1. Activity Design

Activity design issue is attracting educators' and researchers' attention in technology-based education in general (Daher, Abo-Mokh, Shayeb, Jaber, Saqer, Dawood et al., 2022; Daher, Baya'a & Jaber, 2022) and in the STEM classroom in particular (Daher & Shabari, 2020; Teevasuthonsakul, Yuvanatheeme, Sriput & Suwandecha, 2017). Special attention is paid to the integration type of the STEM disciplines (knowledge) in activities: multidisciplinary, interdisciplinary or transdisciplinary. In addition, activity designers took care of the level of inquiry applied in the activity, ranging from highly teacher directed to highly student directed, as described by the National Research Council (2000). The inquiry levels, according to that description, are structured inquiry, guided inquiry, open inquiry and coupled inquiry (Martin-Hansen, 2002). A study conducted by Daher and Shahbari (2020) examined the designs of STEM activities created by pre-service teachers. This study indicated that they had difficulty creating STEM activities for the 'discovery inquiry version' or 'open inquiry version'. The study also mentioned that it was difficult for pre-service teachers to write STEM activities that deal with two dominant disciplines. attempts were conducted related to teachers' designs of STEM activities. Bergsten and Frejd (2019) investigated innovative STEM activities written by secondary mathematics teachers. These researchers examined twenty-first century skills and key concepts from Realistic Mathematics Education and Basil Bernstein's writings to determine that students were given clear instructions regarding what to do, but they were not provided with specific criteria to measure their performance.

Guzey et al. (2016) analyzed teams of teachers who worked together to develop STEM curriculum units and found that many of these units addressed the characteristics of the STEM integration framework. Nicol, Bragg, Radzimski, Yaro, Chen and Amoah (2019) investigated the potential for combining social justice education, skills for the twenty-first century, and STEM education. They focused on the design of potentially rich tasks that engage students to gain crucial knowledge and skills for responding to the complex challenges, both locally and globally.

Southwest Regional STEM Network (2009) described a five-step process of STEM education activity design: Developing the assignment around an actual problem with conditions and limitations provided; clearly describing the objectives of the STEM activity; integrating information about science, mathematics, and technology; identifying and analyzing the key factors that affect the solutions; and discussing the possible design methods.

The purpose of this study is to investigate the similarities and differences between pre-service teacher” designs of STEM activities. Our interest in how pre-service teachers design STEM activities is grounded in our participation as leaders in STEM professional development. Doing so, we represent STEM activities designed by groups of these pre-service teachers who worked collaboratively. The represented activities were designed after the pre-service teacher” participation in a course aimed to introduce STEM education for them. Within the activity analysis, we examine how knowledge, skills and ways of thinking were part of pre-service teachers’ attention when designing STEM activities.

### 3. Theoretical Background

Different models have been suggested for the convenience of STEM education, including a single disciplinary (separate), multidisciplinary, interdisciplinary and transdisciplinary models (English, 2016). Integrated STEM approaches define situations in which two or more STEM disciplines are integrated into one holistic whole. Moreover, the transdisciplinary model integrates the main four topics in STEM, including mathematics, engineering, science, and technology, in the learning process (Anisimova, Sabirova & Shatunova, 2020). This integration offers students a chance to apply math and science concepts in an applied environment through the application of engineering design or/and technology. Through combining rigorous academic concepts with real-life lessons, the interdisciplinary model could connect school, community, work, and the global economy. This connection ensures STEM literacy and prepares the students to compete in the new economy (Southwest Regional STEM Network, 2009). Hobbs, Clark and Plant (2018) identified five models of STEM teaching being used in schools. These are shown in Figure 1.

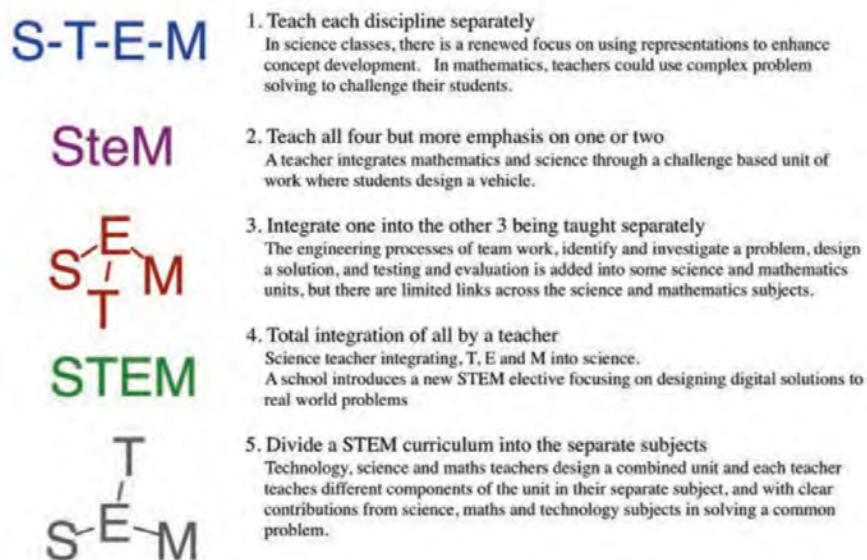


Figure 1. Models of STEM teaching according to Hobbs et al. (2018)

In the STEM field, being aware of not only the knowledge that STEM activities provide for students, but also the skills that they can acquire during their participation is crucial. STEM skills are beneficial in more than one career field (West, 2012). Barcelona (2014) suggests that many skills must be considered in the planning, implementation, and analysis of STEM programs. These skills include collaboration, critical

thinking, creativity, accountability, persistence, and leadership. Different frameworks were provided for the 21<sup>st</sup> century skills. For example, McClure et al. (2017) sorted these skills into four types: Ways of thinking, ways of working, literacy tools for working, and living in the world. Another aspect that teachers should pay attention to, whether when designing or analyzing STEM activities, is the way of thinking requested in the STEM activity (West, 2012). In the current research, we consider STEM knowledge, skills and ways of thinking the constituents of STEM capabilities (Harris, 2012). These capabilities are detailed in Table 1 depending on West (2012).

Knowledge	Skills	Way of thinking
Scientific method, scientific process, knowledge and vocabulary of STEM discipline	investigation, inquiry learning, problem-solving, technical skills, observation, experimentation, quantitative skills, presentations and other practices	Critical thinking, analytical thinking, logical thinking, systematic thinking, structured thinking, questioning, evaluative strategies, independence, reasoning, skeptical approach, objective approach, evidence-based approach, rational, open-minded approach, innovative thinking, creative thinking

Table 1. The STEM capabilities (West, 2012)

#### 4. Research Rationale, Goals and Questions

The present research intends to study the case of STEM tasks by preservice teachers. Doing so, it uses Harris (2012) framework that includes three STEM capabilities: STEM knowledge, STEM skills and STEM ways of thinking. This will give us opportunity to consider different aspects of STEM education, specifically STEM task design.

Little research has been done on STEAM task design, where some research has addressed task case of STEM activities (ex., Daher & Shahbari, 2020). This points at the need for such research. The present research attempts to do so. It investigates task case of preservice teachers when they come to design STEAM tasks. Case our goals, the research questions are:

- First question: What are the knowledge features of STEM task design by preservice teachers?
- Second question: What are the skills features of STEM task design by preservice teachers?
- Third question: What are the ways of thinking features of STEM task design by preservice teachers?

#### 5. Methods

##### 5.1. Research Context and Participants

The designing experiences occurred in a context of a PD program called “Introduction to STEM education”. The PD program was conducted in the academic year 2020-2021. The PD program aimed to develop the pre-service teacher” skills in designing and carrying out STEM activities in the classroom. During the STEM PD program, the pre-service teachers worked in groups to perform three tasks: (1) Presenting a STEM related article to the whole group, (2) Searching for a STEM activity, evaluating it and presenting it to the whole class, and (3) Designing STEM activities. Within the first task, the pre-service teachers prepared a portfolio that included reflections about the different presentations. Within the second task, the presenters were asked to answer some questions after they presented the STEM activity to the whole class. For example, these questions included: “How could you improve the presented activity”, “Would you implement the presented activity in your class? Why and how”. Within the third task, the groups were requested to design a STEM activity\unit that integrate at least three STEM disciplines. As it turned to be, their design included also art.

18 pre-service elementary preservice teachers (6 groups) participated in the PD program. Each group included three preservice teachers who worked together throughout the PD program. Three groups were our focus in the present study.

## 5.2. Data Collecting Tool

Three written STEM units of three groups were chosen to be analyzed. The units targeted the following topics: The Fibonacci sequence, the Konigsberg bridges, and the paper planes. Each unit included at least three different activities. More details about the content of these activities are described in the findings.

## 5.3. Data Analysis

We analyzed the STEM units and activities based on the STEM capabilities, which are three components: STEM knowledge, STEM skills, and STEM ways of thinking (Harris, 2012) as describe in West (2012). STEM knowledge includes four disciplines: Science, technology, engineering and mathematics. Following are theoretical and procedural definitions related to the other two components of STEM capabilities, i.e., STEM skills and ways of thinking.

### 5.3.1. STEM Skills

*Research.* The research skill is divided into three parts: research definition, research design and application writing. Research design is composed of: formulate investigative questions, identify required data and its type, data source, identify unit of analysis and determine appropriate strategy, choose data collecting method, choose data analysis and evaluate time/cost (Ssegawa & Rwelamila, 2009).

*Learning and inquiry.* This skill is composed of: asking questions, searching for information, designing investigations, performing the investigations, analyzing data to make conclusions, using artifacts, and communicating results (National Research Council, 2000).

*Problem-solving.* Identifying concepts for solutions (Harris, 2012).

*Technical skills.* Operating technological tools. This would include the understanding of the nature of the problem to fit technological tools for it (Siekmann & Korbel, 2016).

*Observation.* Obtaining necessary information for making inferences that lead to decisions (Boehm & Weinberg, 1997).

*Experimentation.* This skill is related to designing experiments. The experimentation process involves performing observations that serve as evidence related to hypotheses (National Research Council, 2007).

*Quantitative skills.* Applying mathematical and statistical thinking in a specific situation (Reid & Wilkes, 2016).

*Presentations.* Preparing a topic within a specific time limit and standing in front of others to deliver it (Bouraoui, Moumed & Kaouache, 2016).

### 5.3.2. STEM Ways of Thinking

*Problem solving.* The process by which a student finds a solution to a specific problem situation (Robbins, 2011).

*Analytical thinking.* Investigation of ill-defined situations that involves inquiry (Robbins, 2011).

*Reasoning.* The process of manipulating reasons to fit the conditions of a problem is a core aspect of both problem solving and analytical thinking (Robbins, 2011).

*Systemic thinking.* Understanding how parts are interconnected and comprise a bigger picture (Espejo, 1994).

*Structured thinking.* identifying the parts of the problem that need more attention. (Metwalli, 2021).

*Logical thinking.* The process of getting and putting in a successive order the givens and solution of a problem (Sezen & Bülbül, 2011).

*Questioning.* asking questions about content (The University of Tennessee at Chattanooga, 2021).

*Evaluative.* A process of evaluating data that allow one to arrive at judgments in a transparent way (Vo, 2013).

*Evidence-based.* the process of clear and thoughtful use of evidence from multiple resources (Barends, Rousseau & Briner, 2014).

*Rational.* The process of realizing the importance of reasons (Han, 2002).

*Open-minded.* The process of revising and reconsidering one’s views” (Hare, 1979).

*Innovative.* The process of performing changes to something by presenting something new (Barak, Morad & Ragonis, 2014).

*Creative.* Generating different types of ideas, employing ideas in unusual ways and making unconventional connections that could meet a specific goal (Ramalingam, Anderson, Duckworth, Scoular & Heard, 2020).

*Critical thinking.* The process of interpretation, analysis, evaluation, inference, explanation and self-regulation.

## 6. Findings

In this section, we present the analysis of the three units: The “Fibonacci sequence” unit, the “Konigsberg bridge” unit and “Paper plane” unit. For the first unit, we present a table that shows the STEM capabilities analysis of the different unit activities. Then, we elaborate more about how STEM capabilities appear in these activities. For the other two units, we present first the unit activities and then a table that presents the STEM capabilities analysis of the different unit activities. Finally, we compare the similarity and difference between pre-service teacher” STEM activity designs.

### 6.1. The “Fibonacci Sequence” Unit Analysis

Table 2 shows the analysis of the “Fibonacci sequence” activities in terms of knowledge, skills, and ways of thinking.

<b>STEM Capabilities</b>			
<b>Learning unit</b>	<b>Knowledge</b>	<b>Skills</b>	<b>Ways of thinking</b>
First activity- Exploring the “Fibonacci sequence” and the golden ratio	Mathematical knowledge	Individual inquiry Problem solving Technical skills	Structured
Second activity- Exploring the use of the golden ratio in historical buildings	Engineering and mathematical knowledge	Collaborative learning and inquiry Problem solving Technical skills Presentation skills	Analytical Evidence-based
Third activity- Exploring the existence of the golden-ratio in the nature	Scientific and mathematical knowledge	Collaborative learning and inquiry, problem solving, technical and presentation skills	Analytical Evidence-based
Fourth activity- Exploring the use of the golden-ratio in technological devices	Technological and mathematical knowledge	Individual inquiry, problem solving, technical skills	Structured Evidence-based
Fifth activity- Designing a golden-ratio based drawings	Technological, art and mathematical knowledge	Individual inquiry, technical skills, observation, experimentation	Systematic followed by creative Evidence-based
Sixth activity- Building a golden-ratio based simulation describing closing a palm	Mathematical, engineering, scientific and art knowledge	Individual inquiry, technical skills, observation, experimentation	Systematic followed by analytical Evidence-based

Table 2. The “Fibonacci sequence” activities analysis

Below, we detail the analysis of each activity of the Fibonacci sequence. We firstly write the activity and then analyze it.

**1. Use the internet sites below and find out what the fibonacci sequence is, what it is based on and in which areas it is expressed**

In the previous activity, the students are expected to use enquiry, based on internet sites, to solve the given problems on the “Fibonacci sequence”. Doing so, the students use their technical skills of ICT literacy and data analysis (including verbal and visual analyses) to solve the given problem, which is the definition of the “Fibonacci sequence”. The students use structured thinking to compare and combine between the different texts to define “Fibonacci sequence”. In the first activity, the students are expected to learn mainly mathematical knowledge related to the “Fibonacci sequence”.

**2. The class should be divided into four groups. Each group needs to explore a historical building in relation to the golden ratio. At the end, each group presents its findings to the class. You should search for buildings located in the following countries: Egypt, Mexico, France and Morocco**

In the second activity, the students are expected to inquire collaboratively the use of the golden ratio in several historical buildings, based on the image of the building in the country they chose. Doing so, the students use their technical skills of ICT literacy and data analysis (including verbal and visual analyses) to solve the given problem. In addition, the groups use their presentation skills to show the whole class their findings. In this activity, the students use analytical thinking to analyze the measurements of the buildings. Moreover, based on their images, they investigate the buildings according to the golden ratio. So, this investigation is an evidence-based investigation. Here, the students are expected to combine between mathematical and engineering knowledge related to the “golden ratio”.

**3. The class should be divided into five groups. Each group needs to explore first the “fibonacci sequence” and then the “golden ratio” in the nature. at the end, a representative of each group presents the findings to the class. A member from each group should use the mobile phone to take pictures**

The analysis of the third activity is like the analysis of the second activity, but it is different in two values. Instead of engineering as part of their knowledge, we have here science as the discipline in which the students will be engaged, in addition to mathematics. Moreover, instead of technical skills related to in-door learning using internet sites, the students here need to have skills related to out-door learning in the nature.

**4. Describe technological devices, in the field of aesthetics, in which the golden ratio is used**

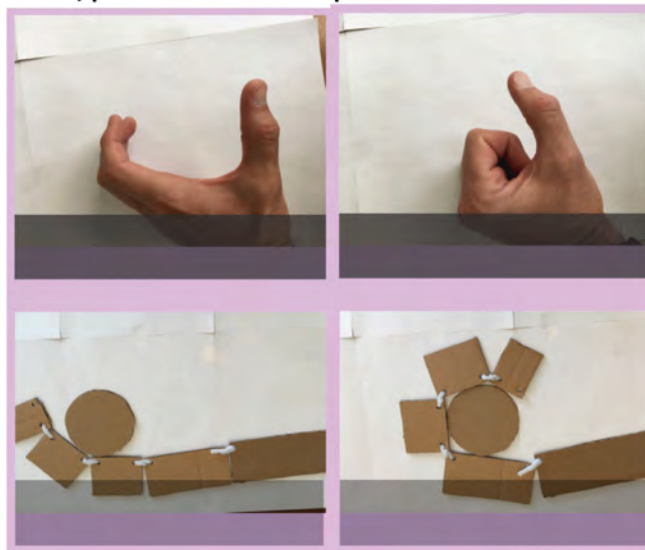
In the fourth activity, the students are expected to search, using the internet, for technological devices that use the golden ratio in the aesthetic field. Doing so, the students use their technical skills of ICT literacy and data analysis — including verbal and visual analyses, to solve the given problem (The use of the golden ratio in technological devices in aesthetic). In the fourth activity, the students use structured thinking as they compare and combine the data that they found in different internet sites. Here, the students are expected to combine between mathematical and technology knowledge related to the “golden ratio”.



5. Watch the video (<https://youtu.be/TiqisSsrSGg>) and try to understand the method of drawing the golden spiral using the “Fibonacci sequence” and the golden ratio. Explain how the “Fibonacci sequence” appears in the golden spiral. In addition, watch how the “Fibonacci sequence” and the golden ratio are used in designing the twitter logo. Afterwards, use the PowerPoint to draw a “picture” based on the golden ratio

In general, this activity aims to show the use of the golden ratio in art through blending technological tools. Here, the students are expected to learn, through a video tutorial, the method of drawing the golden spiral through the geometric representation of the Fibonacci sequence. In doing so, the students use their technical skills of ICT literacy and data analysis (visual analyses). They also use their observations to recognize the method of drawing logo using the “Fibonacci sequence” and the golden spiral. The students are requested to experiment drawing a different logo through the PowerPoint. Here, the students are expected to use the evidence-based, systematic and creative ways of thinking. They are engaged in evidence-based thinking when watching the related video to recognize the method of using the golden spiral in designing a logo. They use the systematic way of thinking when trying to apply the recognized method. They use the creative thinking when trying to modify the recognized method to fit their new drawing. In the fifth activity, the students are expected to combine between mathematical, technology and art knowledge related to the “golden ratio”.

6. Observe the following simulation and build a similar one using the appropriate materials. Explain the scientific phenomenon which is represented by this simulation. Explain how the golden ratio\spiral is related to this phenomenon.



The analysis of the sixth activity is similar to the analysis of the fifth activity, but it is different in two values. The students are not required to learn new technological knowledge, but instead they are required to learn engineering and scientific knowledge that is related to the palm’s structure and its closing. In addition, here the students are not engaged in creative thinking but in analytical way of thinking when identifying the relation between the “Fibonacci sequence” and the presented simulation.

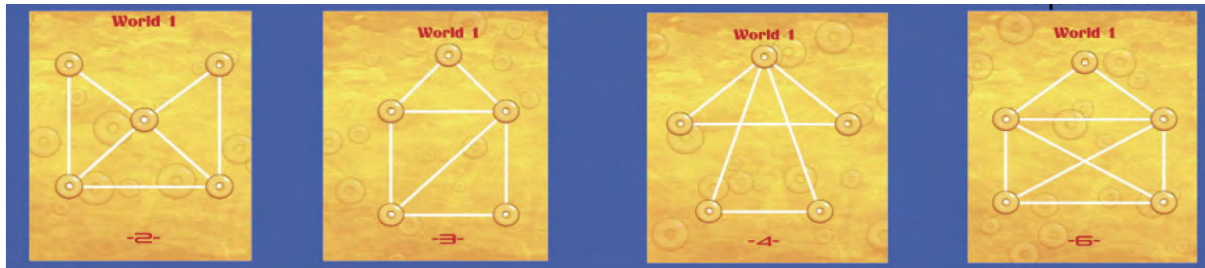
### 6.2. The “Konigsberg Bridge” Unit Analysis

Firstly, the “Konigsberg bridge” unit activities will be described.

1. Open the “ONE TOUCH CONNECT DOT” application and solve the following stages:

World 1 → 2, 3, 4, 5 and 6 stages

When you end the stages, write which stages you succeeded to complete and which ones you did not succeed to complete. Write the strategies that you used. what conclusions have you arrived at?



2. Use the internet sites and find out what the “Konigsberg bridges problem” is, and what mathematical knowledge it is based on. Relate this problem to the first activity.
3. Build a system of at least five bridges (above a water resource). Arrange the bridges so that it is possible to pass each bridge one time and return to the first point. Auler rules in the video could help you in your building process. Decide which material to use for building the system of bridges. Pay attention to fit the properties of the used materials to the system that you are building. Finally, present the built system to the class and show the path that satisfies the conditions. Explain your way of thinking in building the system.

Table 3 shows the analysis of the “Konigsberg bridges” activities in terms of knowledge, skills, and ways of thinking.

STEM Capabilities			
Learning unit	Knowledge	Skills	Ways of thinking
First activity- Exploring strategies to draw a one-way direction path that traverses lines that connect given dots	Mathematical knowledge	Individual inquiry, problem solving, technical skills	Analytical Evidence-based
Second activity- Exploring one-way paths in graphs	Mathematical and Engineering Knowledge	Individual inquiry, problem solving	Structured followed by analytical
Third activity- Exploring strategies to build a system of bridges	Engineering, art and mathematical knowledge	Collaborative learning and inquiry, problem solving, observation, experimentation, technical skills Presentation skills	Critical thinking Innovative Evidence-based Evaluative

Table 3. The “Konigsberg bridge” activitie” analysis

The two units are similar in that the first activity, in each unit, refers just to mathematical knowledge. Moreover, the activities in the two units are based on various STEM skills and way of thinking. In addition, the “Konigsberg bridge” unit is different from the “Fibonacci sequence” unit in the knowledge and ways of thinking it includes. In detail, the “Konigsberg bridge” unit does not include a science topic to learn, whereas the “Fibonacci sequence” does. In addition, all the activities except the first one in the “Fibonacci sequence” unit used integrative approach by combining at least two disciplines. On the other hand, in the “Konigsberg bridge” unit, two of three activities use a discipline-specific approach referring just to mathematical knowledge. Regarding the “way of thinking”, solving the activities in the “Konigsberg bridge” unit needs using critical thinking, while “Fibonacci sequence” unit does not emphasize this way of thinking. The “Fibonacci sequence” unit involves the systematic way of thinking while the “Konigsberg bridge” does not involve this way of thinking.

### 6.3. The “Paper Plan” Unit Analysis

Firstly, the “paper plan” unit activities will be described.

The “paper plan” unit activities

1. **Watch the “Paper Plane” film (<https://youtu.be/Icyj77cMniU>). Search, in groups, for information about conditions that influence paper planes flight. Raise a conjecture how to design a paper plane that flies the longest distance in the shortest time. You should consider one of the two conditions: distance and time.**
2. **Examine the raised conjecture by building at least three paper planes and examining their flights. Choose appropriate materials for examining the conjecture. You can arrange the data in related tables.**
3. **Present your findings to the class in 15 minutes. and discuss these findings with your classmates.**
4. **Examine the effect of air conditions on the paper planes flight: Raise a conjecture, design planes, examine the conjecture.**
5. **Write a reflection regarding the concepts that you learned and the processes that you performed during the different activities. Present this reflection to the whole class.**

Table 4 shows the analysis of the “paper plan” activities in terms of knowledge, skills, and ways of thinking.

The three units were similar in using the four disciplines of STEM . In addition, the three units utilized problem solving as a skill that needs to be used by students. Moreover, the three units utilized evidence-based way of thinking as well as analytical and structured way of thinking.

The units were different in that the first and second units addressed mathematical knowledge throughout all the activities of the unit, while the third unit addressed the mathematical knowledge only in part of the unit activities (2 of 5 activities). In the third unit, the mathematics was utilized as a tool that helped learning engineering and scientific knowledge. In addition, technological knowledge was addressed only in the Fibonacci sequence unit.

The third unit addressed clearly the research skill as it requests students, in the second and fourth activities, to use this skill by it different phases: observation, conjecture, experimentation and observation, analyzing and conclusion. The first and second units did not address clearly the research skill, though it was expected to be used in these units. Specifically, in the second unit, the students were expected to conjecture the way in which they have to arrange a number of bridges to form a one-way path.

<b>STEM Capabilities</b>			
<b>Learning unit</b>	<b>Knowledge</b>	<b>Skills</b>	<b>Ways of thinking</b>
First activity- Raising conjectures	Engineering and scientific knowledge	Observation, research related to conjecturing	Evidence-based Questioning
Second activity- Examining the raised conjectures	Engineering, scientific and mathematical knowledge	Research, problem-solving, Observation and experimentation, technical skills, quantitative skills learning and inquiry	Analytical Critical thinking Evidence-based
Third activity- Presenting and discussing the findings	Engineering and scientific knowledge	Presentations skills, Research, learning and inquiry, problem-solving	Analytical Structured Evaluative
Fourth activity- Examining the air condition “influence on the paper plan’s” flight	Scientific and mathematical knowledge	Research, problem-solving, Observation and experimentation, quantitative skills learning and inquiry	Analytical Critical thinking Structured Evidence-based
Fifth activity- Summarizing the unit	Scientific and Engineering knowledge	Presentation skills	Structured Evaluative

Table 4. The “paper plan” activities analysis

## 7. Discussion

In light of the literature, Daher and Shahbari (2020) suggest that the design of STEM activities should consider two elements: The inquiry level of the activity and the integration of the disciplines of STEM. They described four types of integration: Combining two disciplines with one dominant discipline, combining three disciplines with one dominant discipline, combining two dominant disciplines, and combining at least three disciplines, where two of them are dominant. Below, we discuss the two aspects as presented in the three units described in the findings section. We do that by addressing each of the three aspects of design discussed in the present paper: knowledge, skills and ways of thinking.

### 7.1. The Knowledge Aspect of STEM Activity Design

The research results indicated that the “Fibonacci sequence” unit included activities of different types in terms of the knowledge types. The first activity included one discipline; mathematics, while the second to fourth activities included two disciplines. The fifth activity included three disciplines, while the sixth activity included four disciplines. In all the activities, except the first, at least two disciplines were dominant. For example, in the second activity (Exploring the use of the golden ratio in historical buildings), the mathematics and engineering knowledge were dominant. Overall, the mathematics, the engineering, the science, and the technological disciplines were dominant throughout the activities. The same argument could be said regarding the “Konigsberg bridge” and the “paper plan” units. Specifically, in the “Konigsberg bridge” unit, the mathematics and engineering disciplines were primarily dominant, while in the “paper plan” unit, the science and the engineering disciplines were dominant, where the mathematics disciplines supported them. The previous results point at the different possibilities that STEM education can afford for task design in terms of the integration of disciplines (Daher & Shahbari, 2020; McCurdy, Nickels & Bush, 2020). In the “Fibonacci sequence”, the art discipline was also part of the unit, turning the STEM education into STEAM one (Zubaidah, 2019).

### 7.2. The Skills Aspect of STEM Activity Design

The research results showed that the individual learning prevailed in the tasks designed by the pre-service teachers more than the collaborative learning, which could point at a shortage of the task design reported in the present research. This shortage is emphasized in light of the emphasis of previous studies that collaborative learning in STEM education could support the implementation of STEM tasks (Wang & Shen, 2021).

The 'Fibonacci sequence' and "Konigsberg bridge" units did not address explicitly the research skill, though this skill is expected to be used in these units. Specifically, in the "Konigsberg bridge" unit, the students were expected to conjecture the way in which they have to arrange a number of bridges that result in a one-way path. The third unit addresses explicitly the research skill as it requests students, in the second and fourth activities, to use this skill by its different phases: observation, conjecture, experimentation and observation, analyzing and conclusion. This explicit referring to the research skill could be explained by the science discipline being dominant in the unit, where the previous phases of research are used particularly in the science discipline (Oguz & Yurumezoglu, 2007).

### **7.3. The Ways of Thinking Aspect of STEM Activity Design**

Analytical and evidence-based ways of thinking prevailed in the three units. Generally, applying analytical strategies to solving problems could result in improved solutions (Baumann & Kuhl, 2002). Brown et al. (2011) connected between analytical thinking and STEM education. STEM education is viewed by proponents as a positive factor for student" problem-solving, critical thinking, and analytical skills. The present research findings indicate that STEM task design utilize analytical thinking, as it could support the learners in the problem solving that the individual student or the group of students perform. This support comes from the processes in which the analytical thinking involves as inquiry processes (Robbins, 2011).

Researchers pointed at the role of evidence-based way of thinking in STEM education. Baumann and Kuhl (2002) say that evidence-based teaching is associated with increases in student learning and engagement. Baumann and Kuhl (2002) found that support for teachers increased their implementation of evidence-based STEM education. The previous findings point at the importance of support for in-service and pre-service teachers to design evidence-based STEM activities for implementation in their classrooms.

## **8. Conclusions**

The present study examined pre-service teacher" design of STEM learning units. The research results indicated that different disciplines were dominant in the three designed STEM units. This implies that teachers could design STEM tasks in which different disciplines are dominant, based on their needs and goals. This shows the potentialities of STEM tasks to provide the teacher with flexible resources that serve her or his needs and goals.

The research results indicate that the individual learning was part of the task design by the pre-service teachers more than the collaborative learning. These results point at the need for design of STEM activities that involve collaborative learning. Education programs in STEM education need to pay this issue special emphasis.

The research results showed that preservice teachers used analytical and evidence-based thinking to design STEM tasks within all three units, showing the importance of these ways of thinking for STEM instruction. Thus, in order to design STEM tasks, in service and preservice teachers would benefit from these two types of ways of thinking, possibly in combination with others.

As a result, it is clear that the preservice teacher experienced a new teaching methodology successfully (Baya'a, Daher & Anabousy, 2019; Daher, 2015), here the STEM methodology, which points out the importance of professional development programs that expose teachers to new methodologies and technologies (Abuzant, Ghanem, Abd-Rabo & Daher, 2021; Anabousy & Tabach, 2019; Daher, 2014).

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