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Research Article

Creating learning environments with origami: Experiences of pre-service mathematics teachers

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Using origami in the classroom, this study examines the experiences of pre-service middle school mathematics teachers. A case study model was employed in this study as a qualitative research approach. The study involved 39 senior pre-service mathematics teachers. Document analysis, semi-structured interviews, and observation techniques were used to collect data using the triangulation method. Content analysis was used to analyze the data. During their micro-teaching with origami, pre-service teachers preferred learning outcomes focused on geometry. Most participants used origami to teach learning outcomes that were appropriate to their grade levels and learning outcomes. Throughout all the lesson plans prepared according to the 5E model, origami was used to construct mathematical concepts during the exploration step. While some groups utilized origami folding techniques to explore geometric structures, others used rulers or goniometers instead, indicating that origami is partially effective. In order to improve teacher training programs, more practice should be given with origami-based visual proofs of geometric structures. In addition to contributing to professional and personal development, the participants' opinions showed that this process was beneficial to them. Students struggled to explain origami's steps, as well as selecting models and exploring concepts with origami. For pre-service teachers to overcome these challenges, more time must be allocated during their practicum process within the teaching practice courses so that they can practice teaching mathematics with origami in real classroom settings.

Keywords: Origami; 5E model; Mathematics education

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1. Introduction

The use of origami in various lessons has recently gained popularity (Duatepe-Paksu, 2016). Origami has therefore been increasingly researched in the literature recently as a method of teaching (Arslan, 2012). Since it has vast mathematical potential when used in instruction, it has become an important research topic in mathematics education (Arslan & Isiksal-Bostan, 2016; Boakes, 2009; Higginson & Colgan, 2001; Robichaux & Rodrigue, 2003). Research reveals that the most common use of origami has been in mathematics instruction (Avcu & Avcu, 2019; Franco, 1999; Golan & Jackson, 2009; Shalev, 2005). Origami has been found to improve the mathematical abilities of students when it comes to mathematics instruction. In particular, it was reported to

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enhance general mathematical abilities such as problem-solving skills (Robichaux & Rodrigue, 2003), spatial skills (Arıcı & Aslan-Tutak, 2015; Boakes, 2008, 2009; Cakmak et al., 2013; Hartzler, 2003) and the use of mathematical language (Cagle, 2009; Cipoletti & Wilson, 2004; Hartzler, 2003; Mastin, 2007; Robichaux & Rodrigue, 2003). Additionally, students, pre-service teachers, and in-service teachers have fun with origami activities, enhancing their affective skills by gaining positive attitudes towards mathematics (Arslan & Isiksal-Bostan, 2016; Boakes, 2009; Cipoletti & Wilson, 2004; Fiol et al., 2011; Higginson & Colgan, 2001). Furthermore, students' fine motor skills improve while folding origami, which develops their psychomotor skills (Tuğrul & Kavici, 2002). Therefore, origami is considered to be an effective method for teaching cognitive, affective, and psychomotor skills in students.

The use of origami in mathematics instruction has many benefits, and teachers are crucial to this process. Teachers are expected to integrate origami into mathematics education and create learning environments combined with origami (Ministry of National Education [MoNE], 2005, 2013; National Council of Teachers of Mathematics [NCTM], 2000). Unless origami is integrated into mathematics instruction, it may not be something beyond a fun activity (Georgeson, 2011). Therefore, it is essential to train pre-service teachers to possess adequate knowledge, ability, and attitude regarding mathematics teaching with origami and engage them in related activities in the pre-service teacher education period. Mathematics educators have recently been investing their efforts in increasing pre-service and in-service teachers' awareness regarding origami in mathematics teaching and developing positive attitudes toward using it while teaching mathematics (Avcu & Avcu, 2019; Ergene et al., 2017). Besides, mathematics educators concentrate on studies examining pre-service teachers’ attitudes and opinions with regard to mathematics teaching with origami (Arslan, 2012; Arslan & Isiksal-Bostan, 2016; Çaylan et al., 2018; Duatepe-Paksu & Boz-Yaman, 2018).

A number of quantitative studies have been conducted to explore pre-service teachers' beliefs and self-efficacy regarding the use of origami in mathematics teaching (Arslan et al., 2013; Arslan & Isiksal-Bostan, 2016; Duatepe-Paksu & Boz-Yaman, 2018). Studies also examine pre-service teachers' opinions after receiving theoretical knowledge on teaching mathematics with origami (Ergene et al., 2017; Ünan et al., 2017). Additionally, there are also studies examining pre-service teachers’ experiences (Avcu & Avcu, 2019; Ergene et al., 2017; Gür & Kobak-Demir, 2017; Köğce, 2020) and challenges (Hacısalihlioğlu-Karadeniz, 2020) after providing theoretical knowledge and having them prepare activities involving mathematics teaching with origami. The studies, however, did not examine the activities that pre-service teachers designed. A critical aspect of these activities is how effectively origami is used to teach mathematics. Even though origami is more commonly associated with mathematics than other subjects, origami is used at the beginning of lessons to attract students' attention (Ergene et al., 2017) or used as an art activity without relating it teaching mathematical concepts (Boakes, 2015; Spreafico & Tramuns, 2019). Additionally, the origami models in these activities should not be selected randomly. Determining a model appropriate for both learning outcomes and grade level in the activities is vital for teaching the learning outcomes and preventing students from being distracted and getting bored. Although this is theoretically discussed in training activities on mathematics teaching with origami, how pre-service teachers perform this should be observed. Therefore, the current study investigated how pre-service middle school mathematics teachers used origami to support learning environments. Therefore, this study evaluated the lesson plans prepared by pre-service teachers and the microteaching performed using these plans. Additionally, pre-service teachers' opinions regarding lesson planning and presentation were examined.

1.1. Theoretical Framework

Origami is the art of folding paper named after the Japanese words "oru" meaning to fold, and "kami" meaning paper (Beech, 2009; Yoshioka, 1963). Origami is categorized as “classical origami” and "modular origami". In classical origami, a single sheet is used, and various animal and object figures can be created by folding the paper. Classical origami involves creating origami models only through folding without any cutting or sticking. On the other hand, in modular origami, similar parts formed out of the same folding practices are combined, and three-dimensional figures and geometric models are formed (Tuğrul & Kavici, 2002).

As in many other areas, origami is utilized in education. Particularly recently, mathematics teaching with origami has been emphasized in mathematics curricula. NCTM (2000) recommended applied activities for students to cognitively visualize representations and transformation regarding two- and three-dimensional structures in line with the principles and standards for school mathematics. For students to understand the characteristics of geometric shapes and structures and their interrelationships and enhance spatial reasoning skills, geometric modeling should be used. Using the art of origami particularly, appropriate models can be formed with geometric structures and shapes. In this respect, mathematics educators reported that students' spatial reasoning skills could be developed thanks to convenient origami models (Cipoletti & Wilson, 2004; Shumakov & Shumakov, 2000). Thus, origami is involved in various countries' curricula. The most comprehensive study was carried out in Israel. The curriculum "Origametria," named after the combination of origami and geometry words, was implemented in about 70 schools in this country, and animated origami folding activities in this curriculum were used to teach geometry. In the mathematics curriculum implemented in Turkey after 2005, mathematics teaching with origami was highly emphasized. Lesson activities using origami are present in these curricula (MoNE, 2005), and it is recommended to teach some learning outcomes with the help of origami activities (MoNE, 2005, 2013).

Origami is associated chiefly with geometry since it includes natural geometric forms, yet it is actually used in all learning areas in mathematics lessons (Cagle, 2009; Cornelius & Tubis, 2009; Demaine & O'Rourke, 2007). Some studies implemented sample origami activities in learning domains such as geometry (Hacısalihoğlu-Karadeniz, 2017), numbers (Cañadas et al., 2010; Coad, 2006; DeYoung, 2009; Pagni, 2007), algebra (Cornelius & Tubis, 2009; DeYoung, 2009; Franco, 1999; Georgeson, 2011; Higginson & Colgan, 2001) and probability (Toyib & Ishartono, 2018). Hence, origami is used in teaching the learning outcomes regarding nearly all mathematics topics. However, what matters is the effective use of origami in teaching the related learning outcomes. First, it is essential to choose the appropriate model for students' levels and teaching the related learning outcome (Cipoletti & Wilson, 2004). Besides, teachers should practice the origami model a few times before using it in the classroom and hence master all the model steps and provide the appropriate instructions for students to create the model (Boakes, 2008). Finally, teachers should offer the correct clues for students to associate the model's steps and the related learning outcomes.

1.2. Conceptual Framework

The literature involves quantitative studies researching the effectiveness of the instruction held with origami. These studies demonstrated that teaching with origami enhanced the spatial skills of students in pre-school (Fiol et al., 2011; Respitawulan & Afrianti, 2019), elementary (Cakmak et al., 2013), lower secondary school (Boakes, 2006), upper secondary school (Arıcı & Aslan-Tutak, 2015), and pre-service teachers (Akayuure et al., 2016). Besides, some studies developed the scales of self-efficacy (Arslan & Işıksal-Bostan, 2016) and belief (Arslan et al., 2013) toward the use of origami in mathematics teaching. Additionally, some studies identified pre-service teachers' self-efficacy and beliefs using these scales (Arslan & Isiksal-Bostan, 2016). On the other hand, qualitative studies on teaching with origami are also present. These studies involve classroom notes aiming to introduce origami activities prepared to teach a specific concept (Hacısalihoğlu-Karadeniz, 2017; Robichaux & Rodrigue, 2003; Wares, 2012, 2015; Wares & Valori, 2020), origami activity design studies for disabled and disadvantaged students (Chen, 2006) and studies introducing technology-supported (such as GeoGebra, Mathematica) origami activities (Budinski et al., 2018; Fenyvesi et al., 2014; Ida et al., 2004; Spreafico, 2017). On the other hand, there are several trends in research on teacher training. The first group includes studies collecting pre-service teachers' opinions after providing them with theoretical knowledge on origami (Gür & Kobak-Demir, 2017; Masal et al., 2018; Ünan et al., 2017). The second line of research had the pre-service teachers design origami activities as well as providing theoretical knowledge and then collected their opinions (Gür & Kobak-Demir, 2017; Köğce, 2020). The final group of research had the pre-service teachers design origami activities and perform them in class, and then examined their opinions regarding this process and its challenges throughout (Avcu & Avcu, 2019; Ergene et al., 2017; Hacısalihlioğlu-Karadeniz, 2020). The studies in the literature did not examine pre-service teachers' mathematics activities designed with origami. In other words, whether pre-service teachers used origami effectively in mathematics teaching after the training provided was not researched. The current study holistically examined the learning environments pre-service mathematics teachers created using the 5E model and origami. In this sense, this study is expected to contribute to the field.

2. Method

This qualitative research study employed the case study design. Case studies holistically examine how factors related to a case (setting, people, events, process, etc.) affect that case or how they are affected by the case in the real-life environment in a certain period of time (Merriam & Tisdell, 2015; Yin, 2008). In this study, the case of mathematics pre-service teachers' creating learning environments supported with origami.

2.1. Participants

The participants were selected through criterion sampling method out of purposive sampling methods. The main criteria in selecting participants included preparing lesson plans based on the 5E model in mathematics teaching in their earlier courses and taking the optional "Mathematics teaching with origami" course in the fourth year of the mathematics teaching program. Besides, the pre-service teachers taking this course were first offered information related to the current study, and they were informed that they could participate based on the voluntariness principle. Accordingly, 42 pre-service teachers took the lesson, and three did not want to participate in the study. Hence, the study participants consisted of 39 senior mathematics pre-service teachers. Of the participants, 7 (17,9%) were male, and 32 (82,1%) were female. In line with the ethical principles, the participants' names were concealed and they were coded as PT11, … , PT15; PT21, … , PT24; PT31, … , PT34; PT41, … ,PT44; PT51, … , PT53; PT61, ... , PT64; PT71, … , PT74; PT81, … , PT83; PT91, … , PT94; PT101, … , PT104. The last number in the codes showed the participant's order in the group, and the first number showed the number of the group the participant was in. For example, the code 'PT52' represented the second pre-service teacher in the fifth group and 'PT104' represented the fourth pre-service teacher in the tenth group.

2.2. Data Collection Tools

The study employed the triangulation method, and the study's data were collected through document analysis, semi-structured interviews, and observation techniques. Accordingly, the data collection tools included a semi-structured observation form, a semi-structured interview form, and the lesson plans the pre-service teachers prepared with origami. These instruments are introduced below.

2.2.1. Observation form

The researcher used the semi-structured observation form to observe the mathematics pre-service teachers' micro-teaching regarding mathematics teaching with origami. The observation form consisted of three parts: learning outcome, model, and implementation of origami. The learning outcome parts included the grade level of the learning outcome, learning domain, and learning sub-domain. In the model part, the characteristics of the origami model were observed. The name of the model, number of steps, number of fine/hard steps, its type, and appropriateness for the grade level and learning outcome were considered. Finally, in the implementation part, the step origami is used in the 5E model, effective use of it, the instruction, time, and other materials provided for constructing the model were observed and noted. The researcher observed the pre-service teachers' teaching for about two lesson hours through non-participant observation. Besides, the observing researcher was a teacher training teaching the pre-service teachers for four years, and this enabled the participants to behave comfortably and created a mutual trust environment. Finally, to prevent data loss and ensure reliability, the pre-service teachers' micro-teaching presentations were video recorded after taking their consent.

2.2.2. Lesson plan

The lesson plans the pre-service teachers prepared with origami were collected after the practice of the lesson plans developed with the feedback provided in the presentations. These lesson plans were used to support the data obtained from semi-structured observation and interviews.

2.2.3. Interview form

The literature was reviewed before preparing the interview form, and the interview questions used in the related studies were examined (Avcu & Avcu, 2019; Hacısalihlioğlu-Karadeniz, 2020; Masal et al., 2018). Then, the researchers prepared the interview form consisting of seven open-ended questions. The researchers paid utmost attention so that the interview questions aligned with the research purpose. They prepared the questions in a clear and straightforward way, and the questions did not include manipulative statements. Additionally, two mathematics and a Turkish educator examined the form to ensure content validity. Thus, a question was removed from the form because it was not directly related to the research purpose, and other questions were improved in terms of language use and clarity. After these arrangements, the semi-structured interview form was finalized with six open-ended questions. The interview was handed to all the participants after completing the training. A trusting atmosphere was established so that the participants could respond to the forms sincerely, and they were provided with adequate time. The response time took about 30-35 minutes.

2.3. Data Collection Process

In this study, within the "Mathematics teaching with origami" course, the history and types of origami were first introduced. Then, classical and modular origami models were formed with the participants, they were examined in terms of mathematics, and they were associated with the mathematics curriculum. Finally, the participants were separated into groups of at least three and utmost five members and asked to prepare a lesson plan using origami and present these lesson plans in the class. The classroom was transformed into a real middle school classroom as much as possible, and the pre-service teachers were asked to behave in line with the targeted grade level. The participants prepared the lesson plans using the 5E model and origami. The groups were free in selecting learning outcomes; however, the learning outcomes had to be from the middle school school curriculum. Similarly, the pre-service teachers were free while forming the groups, and a total of ten groups were formed. A group included five members, seven groups included four, and two groups consisted of three. The three pre-service teachers who did not participate in the study also submitted their lesson plans, but their plans were not included in the study. The implementation took fourteen weeks, each week including a three-hour course.

2.4. Data Analysis

2.4.1. Analysis of observation data

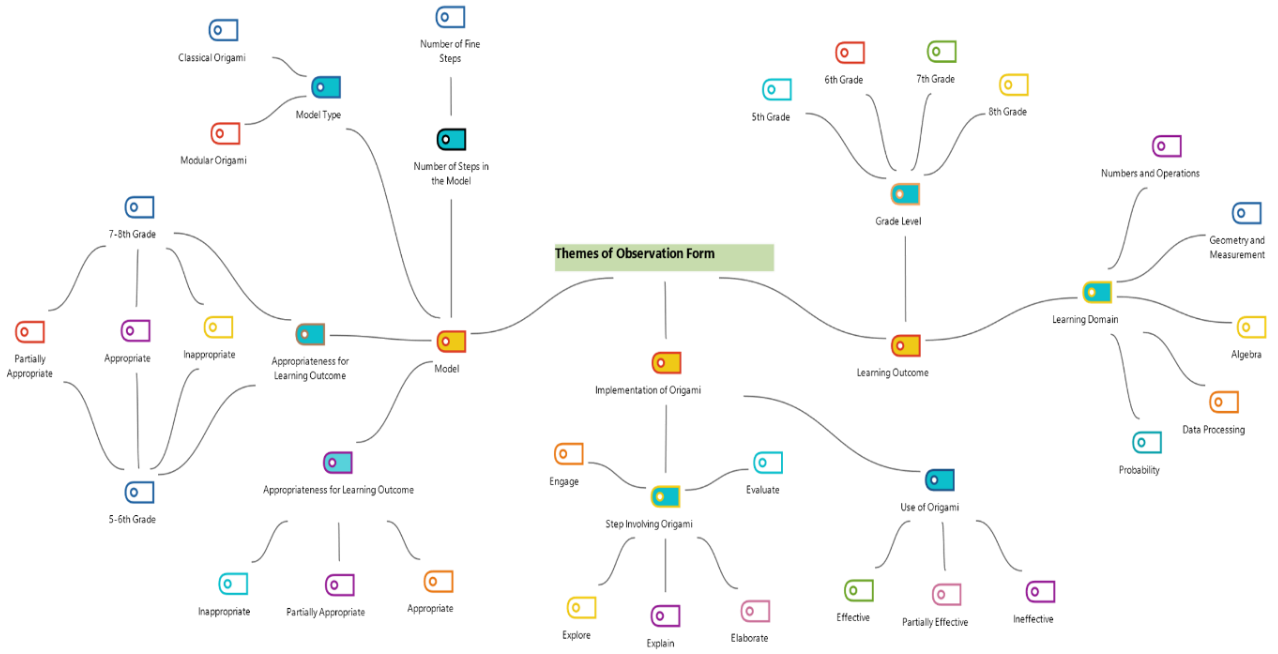
The video recordings of the pre-service teachers' micro-teaching presentations were transformed into Maxqda qualitative data analysis program. The observing researcher and the other researcher examined the recordings independently and coded them in the observation form. In addition, the researchers also examined the pre-service teachers' lesson plans and confirmed their observation notes. The data obtained through the observation form were analyzed using the content analysis method. The two researchers independently analyzed the observation data on the Maxqda program to increase the reliability of the study. After this step, two different Maxqda files were joined in a project, and the percentages of agreement among the codes were calculated. Based on the Agreements/(Agreements + Disagreements) formula, the agreement percentage was calculated as 90.7%. (Miles & Huberman, 1994) recommend that the agreement ratio should be 80% and above.

Categories of grade level and learning domain were formed with regard to the learning outcomes the pre-service teachers preferred in their teaching. Middle school mathematics curriculum was considered while coding in these categories. The grade level was coded as 5, 6, 7, and 8, and the learning domains were coded as Numbers and Operations, Algebra, Geometry and Measurement, Data processing, and Probability.

The categories of the model name, model type, number of steps, appropriateness for the grade level, and learning outcome were formed for the pre-service teachers' origami model in their teaching. The model type was identified based on the literature (Tuğrul & Kavici, 2002), and it was categorized as classical origami and modular origami. Regarding the number of steps in the model, each folding was accepted as a step, and the total of these steps was identified. While identifying the number of fine/difficult steps, the type of folding was considered, and the folding types that pre-service teachers had difficulty with while teaching were taken into consideration. To examine whether the preferred model was appropriate for the grade level, both the total number of steps and fine/difficult steps in the model were considered. The researchers resorted to another mathematics teaching specialist while determining criteria regarding this theme. The observation recordings were watched again, the steps of forming the origami models were paid attention to, and the folding types they had difficulty doing and the time allocated for completing them were evaluated. For this category, 5th and 6th-grade students were considered a group, and 7th and 8th-grade students were considered another group due to differences in their handcraft. While evaluating the appropriateness of the model for the fifth and sixth-grade students, it was coded as appropriate if the number of the steps ranged between one and 15 and the number of the difficult steps ranged between zero and one; partially appropriate if the number of the steps ranged between 16 and 20 and the number of the difficult steps ranged between two and three; inappropriate if the number of the steps was 21 and over and the number of the difficult steps was four and above. For the seventh and eighth graders, it was coded as appropriate if the number of the steps ranged between 1 and 20 and the number of the difficult steps ranged between 0 and 3; partially appropriate if the number of the steps ranged between 21 and 25 and the number of the difficult steps ranged between 4 and 6; inappropriate if the number of the steps was 26 and over and the number of the difficult steps was seven and above. While making this categorization, the number of steps in the model and the number of fine (difficult) steps were considered. In cases where one of these step types was over the expected numbers, the one with the higher numbers was used for categorization. While evaluating the appropriateness of the model for the learning outcome, the codes of appropriate, partially appropriate, and inappropriate were used. It was coded as appropriate when the model included an adequate number of folding for discovering the targeted concept; partially appropriate when it did not include an adequate number of folding or folding practices were adequate for discovering some of the concepts but inadequate for some other concepts; inappropriate when the model did not involve folding for students to discover the concepts.

Finally, the categories of the step involving origami in the lesson plan and the use of the origami model were formed regarding the implementation of origami during the micro-teaching presentation. The pre-service teachers prepared the lesson plans using the 5E model; therefore, while evaluating the step where they used origami, the steps of Engage, Explore, Explain, Elaborate, and Evaluate were used. For the use of the origami model category, effective use of origami during their teaching was examined. It was coded as effective if the concept was taught using folding, putting one side over another, or using fold lines; partially effective if they taught the concept directly by measuring with a goniometer and ruler, although it was possible to teach the concept making use of folding, putting one side over another and fold lines; and ineffective if they did not teach the concept using folding or fold lines and it was not even possible to use them with the model. Figure 1 presents the data analysis framework to demonstrate the analysis process better.

Figure 1
Analysis framework of the observation data



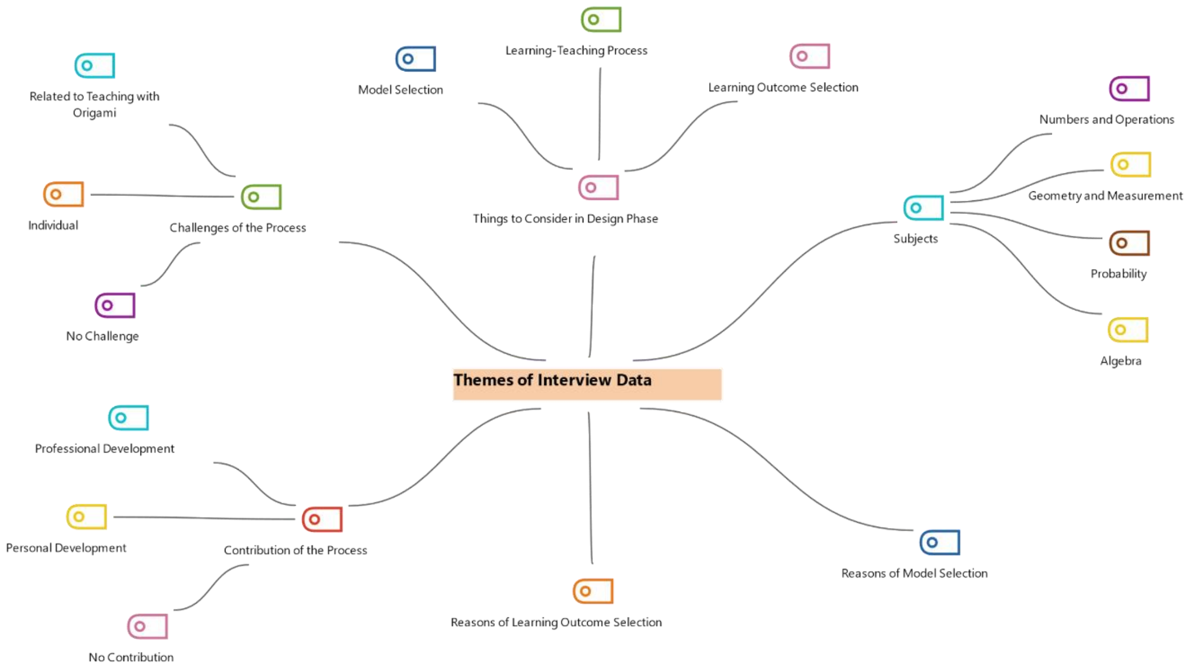
2.4.2. Analysis of interview data

Data from the interviews were first transformed into a computer. The data were analyzed through the content analysis method using the Maxqda program. During the analysis, the researchers read the data carefully and identified codes. The codes were separated based on similarities and differences, and then the related codes were combined to create themes. The analysis resulted in six themes. Figure 2 presents the themes and categories of the interview data.

In the results section, the codes of these themes are presented in schemes together with frequency values. The participants expressed several opinions on some themes, and these opinions were coded separately in the analysis. Therefore, the frequency numbers in the schemes of these themes are more than the total number of participants.

The two researchers analyzed the interview data independently on Maxqda qualitative data analysis program to increase the reliability of the study. Agreements / (Agreements + Disagreements) formula calculation resulted in the value of 99.2%. Miles and Huberman (1994) recommended that the agreement ratio should be 80% and above. The agreement ratio demonstrated that the codes were reliable. Additionally, the researchers avoided interpretation and generalizations during the data analysis process. While interpreting the findings, quotations from the participants were used.

Figure 2
Data analysis framework of the interview data



3. Results

This section includes the findings obtained from the data in tables and figures, respectively. Table 1 presents the characteristics of the origami models the pre-service teachers preferred in their teaching presentations.

Table 1
Characteristics of the preferred origami models

Grade Level	Group No	Model Name	Number of steps in the model	Number of fine steps in the model	Appropriateness of model for grade level: Appropriate	Partially Appropriate	Inappropriate	Model Type: Classical	Modular
8th grade	G1	Hearth	20	6		X		X	
		Fox	20	5				X	
	G3	Frog	20	6		X		X	
	G5	Butterfly	12	3	X			X	
	G9	Flying Duck	15	3	X			X	
		Special Triangles	12	2				X	
7th grade	G2	Cube	11	0	X				X
	G10	Dog	9	0	X			X	
5th grade	G4	Rabbit	24	4			X	X	
	G6	Fish	10	1	X			X	
	G7	Tulip	13	1	X			X	
	G8	Cube	26	7			X	X	
Total					**6**	**2**	**2**	**9**	**1**

Table 1 shows that all the groups preferred different origami models. Eight groups used a single origami model in their teaching, while two groups (G1 and G9) used two origami models. Of the twelve origami models, only one was in modular origami type. The rest were in the classical origami type. However, G7 used sticking in their tulip model, and G5 used cutting in their butterfly model, although these practices are not used in classical origami models.

Four groups used origami for teaching-learning outcomes for the eighth grade, two for the seventh grade, and four for the fifth grade. The appropriateness of the models the groups preferred for the grade level was determined based on the number of steps in the model and difficult folding practices. Accordingly, models in six groups were appropriate, models in two groups were partially appropriate, and models in two groups were inappropriate. The partially appropriate two models were implemented for the eighth grade, and the inappropriate two models were implemented for the fifth grade. The numbers of both the steps in the model and fine steps were a lot.

Table 2
The groups' status of involving origami in their teaching and effective use of origami

	Grade Level				Learning Domain		The step involving origami			Effective use of origami			Appropriateness of model for learning outcome			Other Materials	
Group No	5th grade	6th grade	7th grade	8th grade	Geometry and measurement	Numbers and operations	Explore	Elaboration	Evaluation	Effective	Partially effective	Ineffective	Appropriate	Partially appropriate	Inappropriate	Ruler	Goniometer
G1				X	X		X		X	X			X			X	X
G2			X		X		X				X			X		X	X
G3				X	X		X				X		X			X	X
G4	X					X	X			X			X				
G5				X	X		X			X			X			X	X
G6	X				X		X					X			X		X
G7	X				X		X				X		X			X	X
G8	X				X		X			X			X				
G9				X	X		X	X		X			X			X	X
G10			X		X		X			X			X				
Total	4	0	2	4	9	1	10	1	1	6	3	1	8	1	1	6	7

Four groups preferred eighth-grade learning outcomes, two groups preferred seventh-grade learning outcomes, and four groups preferred fifth-grade learning outcomes. On the other hand, the groups did not select any sixth-grade learning outcomes. Analysis of the learning domains of the learning outcomes showed that only one learning outcome was in the numbers and operations learning domain, and the others were in the geometry and measurement learning domain. None of the groups selected learning outcomes from the learning domains of algebra, data processing, and probability.

The groups prepared the lesson plans based on the 5E model, and all the groups used origami activities in the explore step. Namely, they used origami in structuring mathematical concepts. Additionally, two groups used origami also in another step apart from the explore step. G1 used origami in explore and evaluate steps, and G9 used it in explore and elaborate steps. These two groups also used different origami models for each step. The participants did not utilize origami activities in engage and explain the steps of the 5E model.

In terms of effective use, six groups used origami effectively, three groups used it partially effectively, and one group used it ineffectively. All the groups that used origami effectively in their teaching preferred origami models that were appropriate for teaching the learning outcome. Additionally, two of the three groups that used origami partially effectively (G3 and G7) preferred origami models that were appropriate for the learning outcome, and the models involved a sufficient number of folding practices to teach the concept. However, these groups performed this operation using a ruler or goniometer. The other group that used origami partially effectively (G2) preferred an origami model that was partially appropriate for teaching the learning outcome. Therefore, this group taught the related concept using a ruler and goniometer as opposed to folding practices, and the model they preferred did not involve folding practices for some concepts present in the learning outcome. As seen in Table 2, only one group (G2) preferred an inappropriate origami model for teaching the learning outcome. This group's model did not involve appropriate folding practices for students to explore the related concept. Hence, this group used origami ineffectively in their micro-teaching practices.

Finally, Table 2 demonstrates that some groups used a ruler and goniometer in their teaching. Due to the nature of origami, the equality of geometric shapes or their side length and angle ratio can be identified through the practices of folding and putting one side over another. Therefore, rulers or goniometers are not needed when origami is used effectively in teaching mathematics. Table 2 demonstrates that only three groups did not use these materials. All these three groups used origami effectively. Besides, the other three groups that used origami effectively used these materials to control the cases they made with folding practices. In addition, the three groups that used origami partially effectively used a ruler and goniometer in their teaching. Similarly, the group that used origami ineffectively (G6) taught the contents using only a goniometer due to their preferred learning outcome.

Figure 3
Participants' reasons for preferring learning outcomes

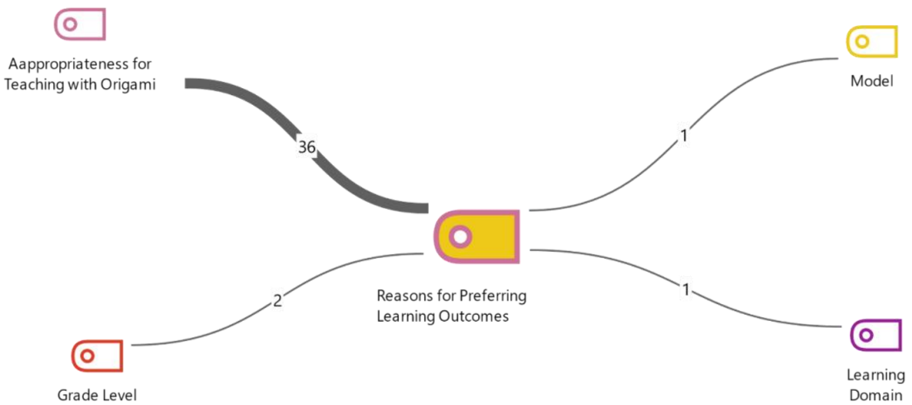
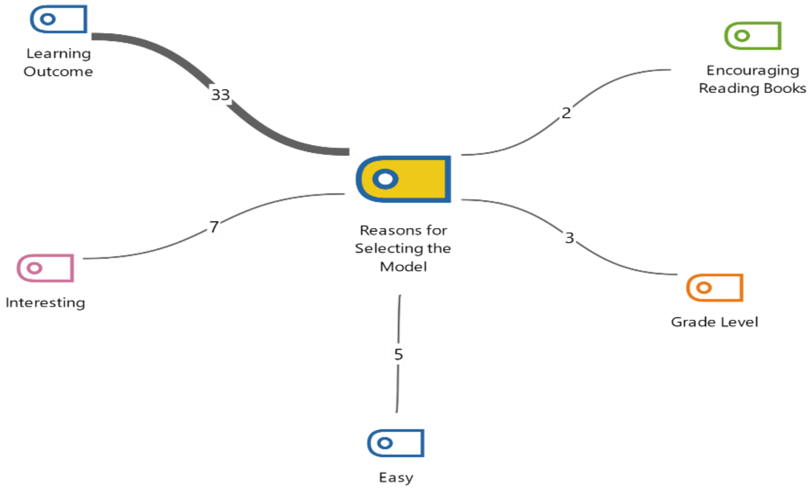


Figure 3 demonstrates that the majority of the participants (f=36) paid attention to whether the learning outcome could be taught using origami while selecting the learning outcomes for teaching mathematics with origami. Additionally, a few participants stated the model they preferred (f=1), the grade level of the learning outcome (f=2), and the learning domain (f=1) as reasons for selecting the learning outcome. In this sense, one of the pre-service teachers asserted that, "We selected this learning outcome because many folding lines could be shown as symmetric lines while making the model, and different symmetric shapes could be formed" (Model-PT12). Another preservice teacher, PT41 stated that "We wanted to be different and did not select one from geometry. We selected one from the numbers and operations learning domain. We selected that particularly because fractions could be taught with origami (Appropriateness for teaching with origami)". PT92 indicated that, "We selected that because we could teach that with origami. Besides, it was an eight-grade learning outcome. We thought that their psychomotor skills would be improved more as they are older (Appropriateness for teaching with origami)".

Figure 4 illustrates the reasons of pre-service teachers for selecting origami model.

Figure 4

Participants' reasons for selecting the origami model



The participants expressed the following reasons for selecting the origami model they preferred for their micro-teaching: appropriateness of the model for the learning outcome (f=33), being interesting (f=7), being easy (f=5), the grade level of practice (f=3) and encouraging reading books (f=2). One of the pre-service teachers, PT15 asserted that "We selected the bookmark (Hearth) model. It was both appropriate for our topic, and it could encourage students to read books (Learning outcome- Encouraging reading books)." Another pre-service teacher, PT31 stated that, "We preferred the frog model because we thought that it could grab students' attention (Being interesting)." In a similar manner, PT62 said "We preferred the fish model. It was appropriate for the learning outcome and students' level (Learning outcome- Grade level)." As a final example, PT74 highlighted that, "We selected the tulip model because it was easy for students to do it, and we could teach the learning outcome with it (Learning outcome- Easy)."

Figure 5 shows the perspectives of pre-service teachers regarding the contribution of lesson plans enriched with origami.

Figure 5

Contribution of the process of preparing and teaching a lesson plan with origami to the participants

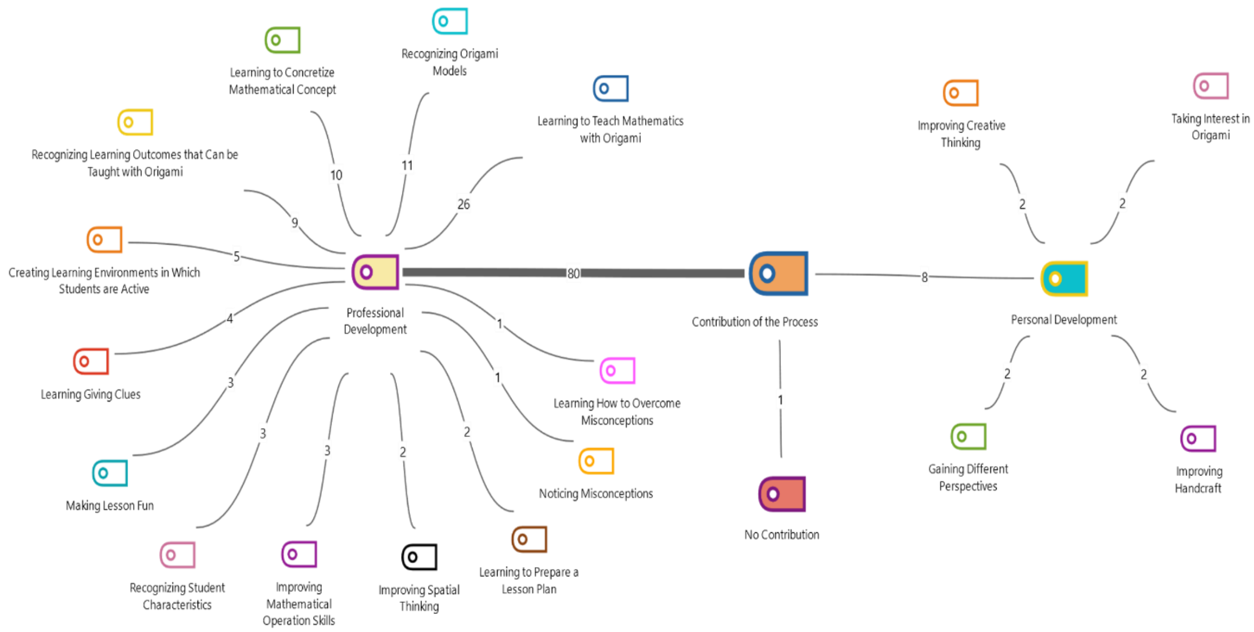


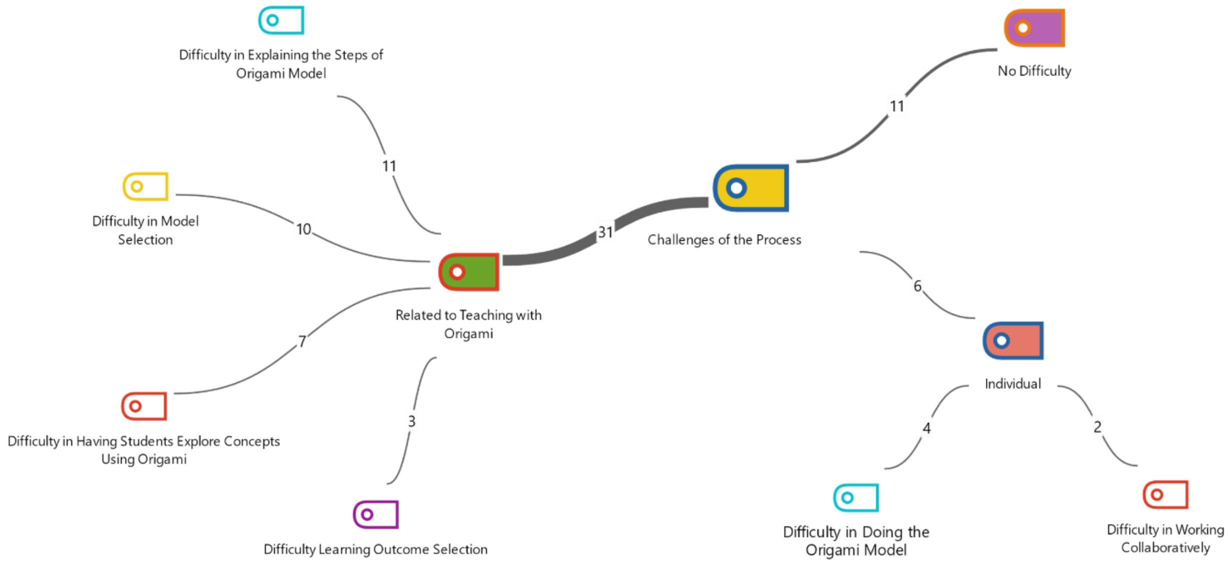
Figure 5 reveals that the participants mostly stated that this process contributed to their professional development (f=80). The contribution of this process included learning to teach mathematics with origami (f=26), recognizing origami models (f=11), learning to concretize mathematical concepts (f=10), recognizing learning outcomes that can be taught with origami (f=9), creating learning environments in which students are active (f=5), learning giving clues (f=4), recognizing student characteristics (f=3), and improving mathematical communication skill (f=3). Additionally, some participants stated that it also contributed to their personal development, such as improving creative thinking (f=2), taking an interest in origami (f=2), gaining different perspectives (f=2), and improving handcraft (f=2). Finally, a participant thought this process did not contribute to him/her.

Based on analyses of direct quotations from pre-service teachers, it appears that PT34, who felt that the process contributed to her/his learning of how to teach mathematics with origami, expressed as: "... I have learned how to teach mathematics with origami.". PT103, on the other hand, stated his/her opinion that this process enabled her/him to realise the outcomes to be taught with origami as follows: "Yes, it contributed to me, I saw that different learning outcomes can be taught with the help of origami...". In addition to this, it was determined that PT82 expressed her/his opinion that the process had no contribution as: "It had no contribution".

Figure 6 posits that the challenges the participants experienced mainly were related to teaching mathematics with origami.

Figure 6

The challenges the participants experienced during lesson plan preparation and the teaching process

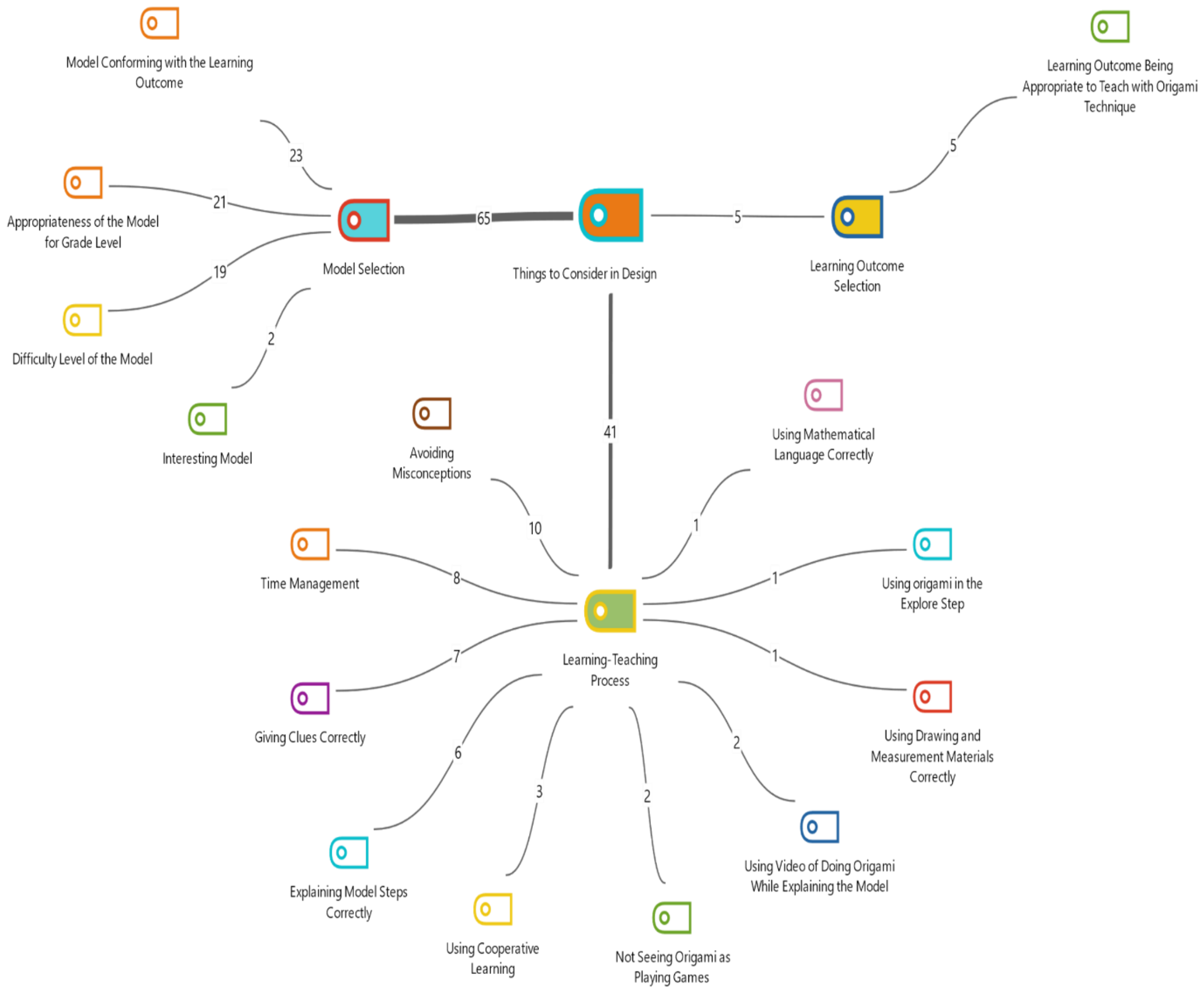


Based on Figure 6, it can be seen that the participants had difficulty in explaining the steps of origami models (f=11), selection of origami models (f=10), having students explore concepts using origami (f=7), and learning outcome selection (f=3). Additionally, some participants had difficulty in working collaboratively (f=2) and creating origami models (f=4) due to their personal characteristics. Finally, some participants (f=11) stated that they had no difficulties in this process.

The following is the direct quotation from PT23, who had difficulty explaining origami steps and choosing a model: "We had difficulty in selecting the most appropriate origami model for the learning outcome. We did not know how to explain while getting students do the origami model". A PT44 who had trouble getting students to explore the subject with origami and to do the origami model, stated, "First, we had trouble getting students to explore the subject with origami. While I struggled with the origami model, my group mates did not. It's not my talent". In addition, PT52 expressed difficulties in collaborating with the group at times. It is hard for me to work in a group. Otherwise, I did not have any significant difficulties.", and reported that he had difficulty working cooperatively with the group at times.

Figure 7 shows the "things" of the pre-service teachers when teaching mathematics with origami.

Figure 7
Things to consider in teaching mathematics with origami



The participants mostly stated that one should be careful in selecting the model for teaching mathematics with origami (f=65). This is followed by the learning-teaching process (f=41) and learning outcome selection (f=5). In model selection, the participants emphasized the appropriateness of the model for the learning outcome (f=23), appropriateness for grade level (f=21), the difficulty level of the model (f=19), and being an interesting model for students (f=2). In the learning-teaching process, they emphasized avoiding misconceptions (f=10), time management (f=8), giving clues correctly (f=7), explaining model steps correctly (f=6), using the cooperative learning method (f=3), and not seeing origami as playing game (f=2). Finally, they stated that the selected learning outcome should fit teaching it with the origami technique (f=5).

PT22, who highlighted considering the learning outcome while selecting the model in mathematics teaching with origami, stated that "The origami model should be related to the learning outcome. We should already consider the appropriateness of the learning outcome for origami." PT61 emphasized the significance of explaining the steps of the origami model correctly with the following statement: "The steps of the origami model should be explained mathematically in a way that the students can understand". Additionally, PT72 told that teachers should pay attention that the model should be both easy and appropriate for the students' level, with this statement: "The origami model should be appropriate for students' development level and grade level. It should be easy."

Figure 8
Subjects appropriate for teaching with the origami method

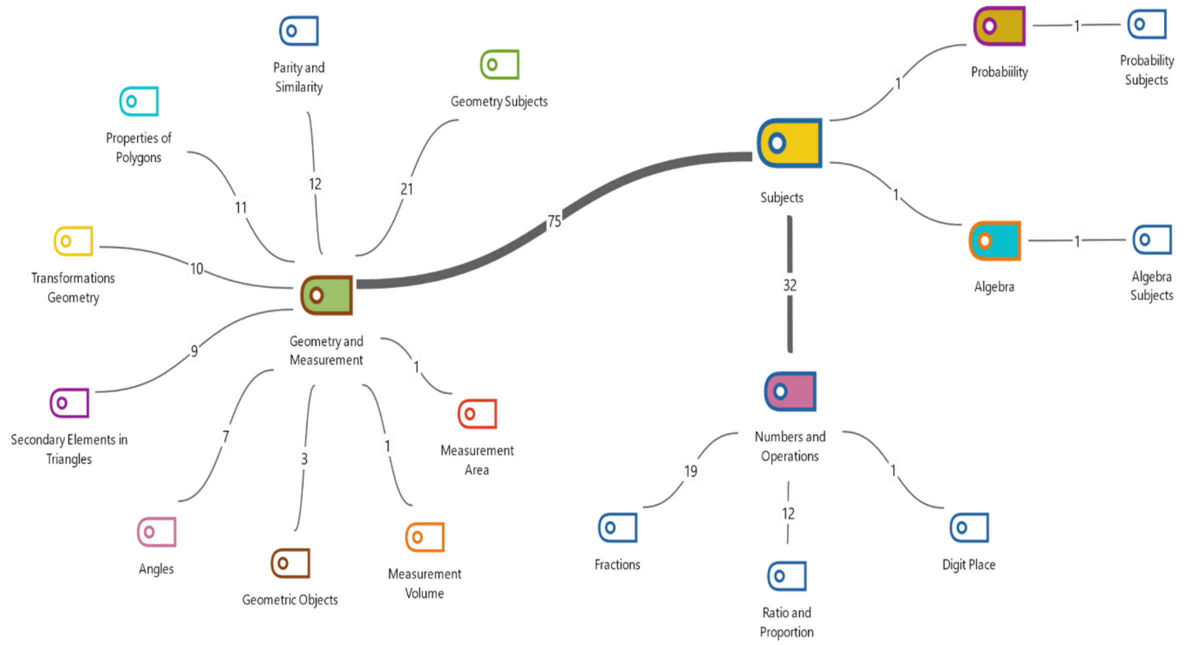


Figure 8 demonstrates that most of the participants thought that origami could be used for teaching the subjects in the Geometry and Measurement learning domain (f=75). They also listed the subjects in numbers and operations (f=32), algebra (f=1), and probability (f=1) learning domains. It is noteworthy that the subjects in the data processing learning domain were not included among the subjects the participants stated as appropriate for teaching with the origami method. Additionally, they also thought that all the subjects in geometry and measurement learning domain (f=21), parity and similarity (f=12), properties of polynomials (f=11), transformation geometry (f=10), secondary elements in triangles (f=9), and angles (f=7) were appropriate for teaching with the origami method. In the numbers and operations learning domain, they listed the subjects of fractions (f=19), ratio and proportion (f=12), and digit place (f=1). It was also stated that all the subjects in algebra (f=1) and probability (f=1) could be taught with the origami method.

The pre-service teachers' opinions were examined. Ö93 stated that origami could be used in geometry and measurement learning domain and said: *"Use of origami may be appropriate in reflection, symmetry, displacement, geometric bodies, parity and similarity, polygons, etc."* Additionally, Ö33 stated: *"Subjects in geometry and probability and ratio-proportion may be appropriate."* Regarding her/his view that origami could be used for more than a single learning domain.

4. Discussion

The learning domains of the learning outcomes the participating pre-service teachers preferred while performing their micro-teaching reveal that the learning outcomes were mostly in the geometry and measurement learning domain, and only one was in the numbers and operations domain. Algebra, data processing, and probability learning outcomes were not selected by participants. Most participants stated that they chose those learning outcomes because they were appropriate to teach with origami. The folding practices of origami bring along various geometric shapes. That is why they chose the learning outcomes, particularly in the geometry learning domain. Mathematics educators argue that several subjects in mathematics can be taught with origami. However, the studies on mathematics teaching with origami involved the learning domains of numbers (Cañadas et al., 2010; Coad, 2006; DeYoung, 2009; Pagni, 2007), algebra (Akan-Sağöz, 2008; Cornelius & Tubis, 2009; DeYoung, 2009; Franco, 1999; Higginson & Colgan, 2001) and probability (Toyib & Ishartono, 2018) while they focus more on geometry domain (Akayuure et al., 2016; Doğan & Bayraktar-Kurt, 2021; Gür & Kobak-Demir, 2017; Hacısalihoğlu-Karadeniz, 2017). Additionally, the participants' opinions regarding the subjects that are appropriate to teach with origami demonstrate that they listed subjects in the geometry and measurement learning domain the most frequently, and they listed the ones in algebra and probability learning domains the least frequently. This result is in line with the learning domains of the learning outcomes that the pre-service teachers preferred in their lesson plans, as highlighted above. However, the majority of the pre-service teachers stated that the learning outcomes in the numbers and operations learning domain are appropriate to teach with origami, but only one lesson plan used a learning outcome from that learning domain.

The pre-service teachers selected learning outcomes from the eighth and fifth grades the most in their micro-teaching with origami, followed by the learning outcomes in the seventh grade. They did not prefer any learning outcomes from the sixth grade. The preferred learning outcomes were expected to be distributed equally among the grade levels. The participants' opinions on the reasons for selecting the learning outcomes show that only two participants selected the learning outcomes considering the grade level. One participant selected the fifth-grade learning outcome thinking that the students in the fifth grade may like teaching mathematics with origami since they are younger. The other participant selected a learning outcome in the eighth grade because students at this age would be more appropriate to teach with origami since their hand muscles are more developed. This finding shows that the pre-service teachers did not consider the grade level a significant criterion while selecting the learning outcomes in teaching mathematics with origami. However, another study that examined mathematics pre-service teachers' micro-teaching with origami found that the subjects were mainly in the seventh and eighth-grade levels, followed by the fifth and sixth grades. Besides, they revealed that the pre-service teachers selected those learning outcomes because three-dimensional models involved longer steps (Doğan & Bayraktar-Kurt, 2021; Ergene et al., 2017). In the current study, the pre-service teachers selected the eighth grade the most and the sixth grade the least in their teaching mathematics with origami but the reasons for selecting the grade levels differed.

Another study result is that more than half of the groups selected appropriate origami models for the grade levels, indicating that the participants were careful in selecting origami models. It was observed that the difficulty of the model, the models including more steps or fine folding practices, in other words, prevented the teaching of related mathematics concepts. It is vital in teaching with origami that the folding steps should be associated with mathematical concepts correctly (Baicker, 2004; Serra, 1994) and instructed using the mathematical language (Sze, 2005). Otherwise, the failure students may experience in completing the model may lead them to feel anxiety during the lesson and then give up. This is supported by the participants'' opinions. Most of the participants stated that they considered the appropriateness and difficulty level of the model for the related grade levels while selecting the models. However, two groups' models were partially appropriate for the grade level, and two other groups' models were not appropriate. Particularly the models that were inappropriate for the grade level were used for the fifth-grade students. The fifth-grade students have the shortest attention span among the middle school students, and they have difficulty forming the model due to muscle development. Analysis of the participants’ opinions revealed that few participants paid attention to grade level in model selection at the beginning and more participants thought that grade level should be taken into consideration in model selection at the end of the semester. Emphasizing the properties of the models used during the micro-teaching presentations may have increased their awareness regarding the origami models.

All the groups used origami in the explore step of the 5E model adopted while preparing the lesson plans. That all groups used origami in this step may be interpreted as that they aimed to have students construct the mathematical concepts mentally using origami. This result means that the participants considered origami as a method of exploration in concept teaching as opposed to an artistic activity. Likewise, a study on preparing and implementing lesson plans based on the 5E model and origami found that high school students enjoyed learning by discovery the most (Boz-Yaman & Bulut, 2019). Based on this result, we can argue that when they attach importance to mathematics teaching with origami, they may use the origami method based on discovery to teach mathematical concepts and hence help students like mathematics lessons. Additionally, two groups in this study used origami in another step as well as the explore step. One group used origami in the elaborate step, and the other used it in the evaluate step. It was observed that using origami in the explore and elaborate steps is very intense and tiring. The group that used it in the explore and evaluate steps gave origami as homework and it was less tiring for students. The participants did not use any origami activities in the engage and explain steps of the 5E model. The research on the 5E model unearthed that as pre-service teachers work with the 5E model, they concentrate more on the explore step and less on engage and explain steps (Sickel & Friedrichsen, 2015). Therefore, this result explains the finding in the current study that the pre-service teachers used origami in the explore step rather than other steps. On the other hand, a study reported that all of the participating pre-service mathematics teachers used origami in the engage step in their micro-teaching presentations (Ergene et al., 2017). This study contradicts the current results.

The current study found that more than half of the groups used origami effectively in their micro-teaching. Besides, of the three groups that used origami partially effectively, two groups could use it effectively because they had selected the origami models in line with the learning outcomes. Therefore, only two groups could not use origami effectively in their teaching due to the models they selected. This finding indicated that most participants had the knowledge and capability to select an origami model appropriate for learning outcomes and teach mathematics with origami based on exploration. However, in a previous study, sophomore pre-service teachers were asked to match the introduced origami models with learning outcomes, and they were not very competent in doing this matching in the first weeks, but they were better in the following weeks (Ergene et al., 2017). This may be because they were second-grade pre-service teachers. The current study employed fourth-grade pre-service teachers. In other words, they had adequate levels of pedagogical content knowledge, and hence they could select the appropriate models in the beginning.

Properties of geometric structures can be visually proven using origami (Duatepe-Paksu, 2016). However, some groups in this study had the students explore the properties of geometric structures using a ruler or goniometer, so they used origami partially effectively. Besides, some groups that used origami effectively visually proved the geometric structures using origami, but they also had the students control this proof using a ruler or goniometer. The literature highlights that teaching properties of geometric structures through getting students to recognize them with the cases like symmetry, pairing, and matching as a result of folding practices in origami is more effective than teaching them through traditional instruction using a ruler or compass (Whiteley, 2005). However, teaching those properties using both origami and a ruler-goniometer provides diversity. It is known that students and pre-service teachers have difficulty in using these materials in mathematics education. Therefore, it is recommended to use materials such as a ruler, angle meter, goniometer, or compass in paper folding activities (Karakuş, 2014).

The study demonstrated that the micro-teaching process contributed to pre-service teachers' professional development in the areas of learning mathematics teaching with origami and origami models, recognizing learning outcomes that can be taught with origami, and learning to give instructions and clues. Few participants stated that it helped them gain different perspectives and enhanced their handcraft. The literature also reports that the process of designing activities with origami contributes to pre-service teachers (Avcu & Avcu, 2019; Hacısalihoğlu-Karadeniz, 2020). Similarly, studies in which pre-service teachers taught with origami reported a change in their attitudes toward teaching with origami (Köğce, 2020) and an increase in their capabilities to use origami in teaching (Ergene et al., 2017).

The study also revealed that the participants had the most difficulty in teaching mathematics with origami. They had difficulty particularly in explaining the model's steps as well as having students explore the concepts, and model and learning outcome selection. Previous research also reports similar results (Hacısalihoğlu-Karadeniz, 2020). Having difficulty in mathematical communication during the micro-teaching is already expected because mathematics teaching with origami is a method on its own. Besides, this method should be used in line with a model, and they should stick to the model's steps. Therefore, the concept that should be taught in the learning outcome needs to be present in the model. Thus, model selection is a challenge in mathematics teaching with origami. Regarding the individual challenges the participants experienced, they had difficulty in constructing the model and working cooperatively. It is noteworthy that some of the participants stated that they had difficulty while constructing the model. Although these pre-service teachers stated that their handcraft was not developed, these models may also be challenging for middle school students. This problem once again presents the significance of selecting an easy-to-do model. In the same vein, the studies in the literature affirmed that students could do the classical origami models more easily and in a shorter time than modular origami models (Hacısalihoğlu-Karadeniz, 2017). In this study, all groups except for one chose classical origami, and few participants stated that they had difficulty while doing the model, indicating that they paid attention to selecting an easy model.

The participants expressed that teachers should be careful most for model selection and then for the teaching-learning process and learning outcome selection. In model selection, they placed most emphasis on harmony between model and learning outcome, and model and grade level as well as selecting an easy and interesting model. Regarding the teaching-learning process, the participants highlighted the significance of avoiding misconceptions in students, time management, giving clues and explaining model steps correctly in teaching with origami. Another study reported that pre-service teachers pointed to model selection, time allocation, classroom population, students' level, and clear instructions and clues in teaching mathematics with origami (Avcu & Avcu, 2019). Although the pre-service teachers in this study did not refer to classroom population, they emphasized cooperative learning method and using the video including the steps of the model. It is thought that the participants recommended them to make it easy to use the origami method in crowded classrooms.

5. Recommendations

As a result of the study, we can argue that the pre-service teachers' capabilities to create a learning environment supported with origami were improved. Namely, the training offered to the pre-service mathematics teachers enabled them to select origami models appropriate for learning outcomes and grade levels and use origami effectively while teaching mathematics. However, it was also observed that some groups had the students explore the properties of geometric structures using a ruler and goniometer as opposed to origami folding practices; namely, they used origami partially effectively. Therefore, teacher training programs should include more practice regarding the visual proof of geometric structures using origami. It is recommended that faculty members practice visual proofs using origami while teaching the field courses such as Analysis and Analytic Geometry in the undergraduate curriculum. Thus, pre-service teachers may be more familiar with mathematics teaching with origami and adopt this method. Additionally, the pre-service mathematics teachers had the most difficulty in explaining the origami model's steps, having students explore the concept with origami and model selection. To overcome these challenges, pre-service teachers should be provided with the chance to practice mathematics teaching with origami in real classroom settings during their practicum process within the teaching practice course. Furthermore, given the contribution of the training for the pre-service teachers in this study, it is recommended to add the "Mathematics teaching with origami" course to the undergraduate curricula of the mathematics teaching program in the education faculties. Besides, professional development seminars on the effective use of origami in mathematics teaching can be offered for the in-service teachers. Finally, a longitudinal study examining pre-service teachers' use of origami in mathematics teaching when they become teachers in the future and the change in their experiences would contribute to the literature.

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