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# Investigating the Development of Preservice Mathematics Teachers' Technological Pedagogical Content Knowledge through Micro Teaching Lesson Study: The Case of Geometric Objects[1]

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**Abstract**: This study aimed to investigate the effect of preservice mathematics teachers' Micro-Teaching Lesson Study (MLS) experiences on their Technological Pedagogical Content Knowledge (TPACK) development for geometric objects in an environment created with a dynamic software (GeoGebra 3D). The research was designed as a qualitative case study and the participants were two preservice mathematics teachers. The data were collected through a semi structured interview form, lesson plans, micro-teaching observations, and interviews conducted after collecting data with each of the specified tools. The data were analysed following a TPACK development model. The results revealed that their TPACK levels increased following MLS experiences. It was observed that this increase was mainly in the lesson plan and micro-teaching findings.

Keywords: *Micro Teaching Lesson Study, Preservice Mathematics Teachers, Geometric Objects, Technological Pedagogical Content Knowledge.*

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## 1. INTRODUCTION

Geometry is an important branch of mathematics and is used for the understanding of space (Galitskaya & Drigas, 2020). The most commonly used geometry is associated with shapes and geometric objects. The topic of geometric objects differs from other geometry topics in that objects are three-dimensional. Seeing and imagining three-dimensional geometric objects as two-dimensional negatively affects students' effective learning of the subject (Uysal, 2013). Moreover, visualizing three-dimensional objects from two-dimensional drawings creates visual obstacles (Widder & Gorsky, 2013). Technology support may be required to overcome these and similar disadvantages, because when teaching is conducted with technology, students can better establish the relationship between concepts and representations in their minds (Tezer & Cumhur, 2019). Moreover, technology also helps

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students to explore authentic geometrical problems and solve problems of everyday life (Hwang, Hoang & Tu, 2020). Studies show that technology-supported teaching of geometric objects has a positive effect on students' success and attitude (Keşan & Çalışkan, 2013; Tutak, Aydoğdu & Akgül, 2015). It also contributes to students' geometric thinking levels (Patkin & Sarfaty, 2012), problem solving (Yıldız, Baltacı & Aktümen, 2012; Widder & Gorsky, 2013), and spatial ability (Ha & Fang, 2013). Furthermore, it positively affects students' perception of geometric objects and dimensions (Altıkardeş & Yiğit-Koyunkaya, 2021). It has also been determined that technology-supported teaching of geometric objects has a positive effect on self-efficacy perceptions (Özçakır & Aydın, 2019), three-dimensional thinking skills (İbili et al., 2020) and learning outcomes (Koparan et al., 2023). Çopur and Türkdoğan (2021) stated that technological materials contribute to students' exploration and understanding of the subject. In addition, technology helps students to understand geometrical content (Auliya & Munasiah, 2019).

One of the technologies that can be used in the teaching and learning of geometric objects is GeoGebra, which is a dynamic mathematics software program designed by Markus Hohenwarter (Hohenwarter & Fuchs, 2004). GeoGebra is an easy-to-use dynamic mathematics software program that combines many aspects of different mathematical software packages (Hohenwarter & Lavicza, 2007). Among the advantages of GeoGebra are that it is multi-lingual and is available as freeware. In addition, the use of 3D provides the opportunity to work easily on geometric objects.

Teachers and teacher educators are also expected to be proficient in technology in order to improve students' skills related to geometric objects. Teacher educators play an important role in developing preservice teachers' technology-enriched teaching practices (Tondeur et al., 2019). Defined as one of the teacher competencies, the Technological Pedagogical Content Knowledge (TPACK) framework requires a teacher to have knowledge in three domains and to understand how this knowledge is used to teach effectively with technology (Koehler, Mishra & Cain, 2013). TPACK is also defined as professional educational knowledge based on teachers' concurrent and interdependent use of content, pedagogy and technology (Harris & Hofer, 2009).

Developing preservice teachers' TPACK is also an important goal of teacher education (Mishra & Koehler, 2006). One of the methods used to develop TPACK is Microteaching Lesson Study (MLS) (Zhou, Xu & Martinovic, 2016). Fernández (2005) stated that the MLS technique leads preservice teachers to think mathematically, experiment and explore relationships. In MLS, preservice teachers work in small and heterogeneous groups. A group usually consists of three members. During MLS, a teaching topic is chosen and a plan is made for teaching it. In accordance with this plan, the group members explain the topic one by one to a student or peer group consisting of 5-10 people for at least 30 minutes. MLS practices create a learning environment that involves active and meaningful discussion, planning and practice. They also ensure support from a knowledgeable advisor, collaborative deliberation, and the opportunity to experiment, analyze and revise (Fernández, 2010). Cavin

(2007) and Kurt (2016) utilized MLS for developing preservice teachers' TPACK and achieved successful results.

This study aimed to develop preservice mathematics teachers' TPACK through geometric objects. For this reason, the MLS technique, which contributes to preservice teachers' development, was used. In addition, GeoGebra software was chosen for working with geometric objects because it is free and easy to use, has a choice of languages, and is suitable for working with three-dimensional objects.

## 2. LITERATURE REVIEW

### *2.1. What Is Technological Pedagogical Content Knowledge?*

The integration of technology into education has increased rapidly in the 21st century (Wijaya, Tang & Purnama, 2020), because the educational mission for this century is to build a knowledge-based society through the integration of Information and Communication Technologies into the learning process (Hernawati, 2019). In addition, in teacher training programs in this age, it is necessary to consider pedagogical knowledge, technology and teaching strategies instead of focusing only on teaching the content (Nuangchalerm, 2020). Similarly Mourlam, Chesnut, & Bleecker (2021) stated that at the center of teacher education, it is necessary to prepare pre-service teachers to teach effectively with digital technologies and media. For this reason, improving teachers' competence in technology integration has been one of the areas of interest in teacher education in recent times (Njiku, Mutarutinya & Maniraho, 2021). Defined as one of these competencies, TPACK offers educational technologists, teachers and teacher educators the opportunity to reevaluate their knowledge and use of technology in the classroom (Cox & Graham, 2009). According to Santos & Castro (2021), TPACK is the effectiveness of teaching the course with technology integration. They also stated that it is an ideal application in all aspects of learning, which is important in the teaching and learning process. TPACK includes seven different types of knowledge bases. These are Content Knowledge (CK), Pedagogical Knowledge (PK), Technological Knowledge (TK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical Content Knowledge (TPACK) (Mishra & Koehler, 2006). TPACK differs from these seven individual types of knowledge and their intersection points in that it consists of multiple interactions of these knowledge types (Harris, Mishra & Koehler, 2009). TPACK provides a dynamic framework for designing, implementing and evaluating teaching with technology in the curriculum. TPACK also requires supporting learning with appropriate information and communication technologies and knowing when, where and how to use domain-specific knowledge and strategies (Niess, 2011).

Various methods and models have been determined for developing and evaluating teachers' and preservice teachers' TPACK (Aldemir-Engin, Karakuş & Niess, 2022). First, research on component development was carried out. The TPACK components were created based on Grossman's (1990) PCK components. These components are:

• An overarching conception of teaching science/mathematics with technology (Niess, 2005): This component is concerned with teachers' knowledge and beliefs about the subject, important things that students need to learn, and teachers' perceptions regarding how technology supports learning (Niess, 2013).
• Students' understandings, thinking, and learning in a subject with technology (Niess, 2005): This component is concerned with teachers' knowledge and beliefs about the extent to which students can learn a certain subject using technology (Niess, 2013).
• Curriculum and curricular materials: This component is concerned with the extent to which teachers can implement various technologies to teach specific subjects and their understanding of how concepts and processes in the curriculum are organized, structured and evaluated in technologically enriched teaching/learning environments (Niess, 2013).
• Instructional strategies and representations for teaching with technologies (Niess, 2005): This component is concerned with teachers' ability to use certain technologies both to represent content and to guide students through the teaching/learning process (Niess, 2013).

After the component identification study (Niess, 2005), studies were conducted to determine the TPACK levels (Niess et al., 2006; Niess et al., 2009; Tatar, Aldemir & Niess, 2018). The TPACK levels are defined as pre-recognizing, recognizing, accepting, adapting, exploring, and advancing. A teacher at the pre-recognizing level has no knowledge of technologies that can be used for learning or teaching, nor of how to use these (Tatar, Aldemir & Niess, 2018). Teachers at the recognizing level recognize and make use of technologies. Teachers at the accepting level have positive or negative attitudes towards teaching or learning with technologies. At the adapting level, teachers have the option to adopt or reject the use of technologies while teaching or learning. At the exploring level, teachers make discoveries together with students by using technologies related to the subject. At the advancing level, teachers and students make active use of technologies by integrating them with pedagogy and content (Niess et al., 2006).

In studies in which levels and components are dealt with together, a model has generally been used, and an attempt has been made to give more meaning to TPACK, which is relatively difficult to structure, measure and evaluate. There are studies in the literature in which a TPACK model is used (Balgalmış, 2013; Lyublinskaya & Du, 2021; Lyublinskaya & Kaplon-Schilis, 2022; Lyublinskaya & Tournaki, 2013; Riales, 2011; Saralar, 2016; Suharwoto, 2006; Taylor-Ivy, 2011).

Bueno et al., (2023) suggest that TPACK should be regarded as a homogeneous blend of knowledge. They have stated that rather than dealing with the seven types of knowledge individually, TPACK should be considered as a special blend of technological, pedagogical and content knowledge. The aim of this is to establish connections between technology, pedagogy and content in the best possible way during the teacher's or preservice teacher's lesson delivery. The image representing this view is shown in Figure 1.

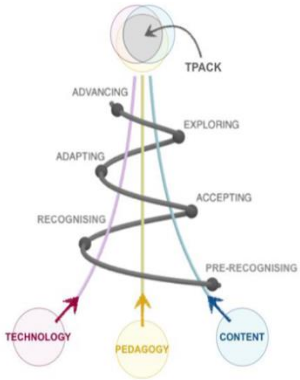


**Figure 1.** *Description of TPCK/TPACK Components Including the Pre-Recognizing Level (Bueno et al., 2023)*

The "TPACK development model for preservice mathematics teachers" (Aldemir-Engin, Karakuş & Niess, 2022) was also used in this study. The model consists of four TPACK components and six levels for each component. The model was designed purely for preservice mathematics teachers and was selected because it was useful for this research. In model studies, TPACK is regarded as homogeneous and also, it is easier to examine development on a level basis.

According to the model, in Overarching Conception component, a preservice teacher at pre-recognizing level doesn't know for what purpose technologies can be used in mathematics education. At recognizing level, technologies are used to make a difference only in the teaching of complex mathematical concepts and operations. And also it is thought that technology is not very necessary, and efficiency does not decrease without of technology. So the use of technology is not embraced unless it is compulsory. At accepting level, technology is used for visualization, calculation, supporting examples, motivation, demonstrating subjects taught in the exact same way with technology, reinforcing, concretizing, reinforcing, making a difference, drawing attention and increasing memorability. At adapting technology in learning and teaching is used for trying out, discovering and applying new approaches to the subject after learning the subject of mathematics in the first place. At exploring level, technology is used for both learning and teaching purposes, but mostly for learning purposes. At advancing level, technologies are used by students to experiment and explore the mathematical concepts and operations so that they can be understood for learning purposes.

In Learning, Thinking, and Understanding of the Students component, a preservice teacher who is at pre-recognizing level doesn't know how technologies can be used for learning purposes in mathematics. At recognizing level, technologies that can be used in mathematics lessons are known. But technologies are not considered as necessary in learning mathematics since they do not improve mathematics learning, mathematical thinking, or reasoning skills among the students. At accepting level, the group uses technology by imitation and does exactly what is said. The group focuses on the problems related to technology use rather than mathematics. At adapting level, he/she believes when the lectured group uses technology after learning about mathematics their understanding of mathematical ideas improves. And technology is used mostly as an addition and sometimes as a complementary tool in the learning. At exploring level, the lectured group explores with technology. They combine technology designs with mathematical thinking and problem-solving. At Advancing level technology is used as a learning tool to develop a deep understanding within the lectured group through high-level thinking activities such as problem solving and project-based activities.

In Curriculum and Curriculum Materials component a preservice teacher at pre-recognizing level doesn't know how technologies can be integrated into the subjects of the mathematics curriculum. At recognizing level, it is thought that without technology, the mathematics curriculum is focused on memorizing rules and operations. And also the pre-service teacher is unsure about how to use technology in the curriculum. And he/she believes curriculum including technology is examined only superficially. At accepting level pre-service teacher says it is difficult to conduct applications with technologies in many different subjects in the mathematics curriculum. Also believes the lecturer has difficulties with technological materials and applications and cannot use technology as originally desired. At adapting level, technological materials are used as both teaching and learning tools (mostly teaching). Believes in the mathematics curriculum, technologies are mostly additional and sometimes supplementary tools. At exploring level technological materials are used as both teaching and learning tools (mostly learning). And technologies have a unifying role as problem-solving tools. He/she has new ideas in the curriculum regarding the use of Technologies. At advancing level, she/he believes when technology is integrated, curriculum reorganization and constant changes are made and new courses are created in order to benefit from effective and efficient learning.

In Instructional Strategies and Presentations component, a pre-service teacher at pre-recognizing level doesn't know how technologies can be used for teaching purposes in mathematics lessons. At recognizing level, he/she thinks that mathematics and technology should be taught separately. He/she knows about technology but doesn't use in lessons. At accepting level, technology use is teacher–centered and he/she use technology with difficulties. At adapting level, the lecturer needs to give direct information with the presentation method (deductive) in technology activities. At exploring level, student-centered activities are carried out by focusing on the group's understanding of mathematics while integrating technology in planning, implementation, and also reflection in learning and teaching. He/she can impact the technological difficulties. Multiple teaching strategies are used with technology. The students in the lectured group discover and reinforce themselves. At advancing levels, the main method is mathematical exploration. Lessons are student-centered and there are inquiries under the control of the lectured group.

### *2.2. Micro Teaching Lesson Study*

Micro-Teaching Lesson Study (MLS) is a combination of micro-teaching and Japanese Lesson Study. Like Lesson Study, which allows teachers to practice, MLS encourages pre-service teachers to develop, implement, analyze and revise their lessons in a collaborative and self-repetitive method (Fernández, 2005).

According to Fernández (2010), MLS is a pedagogical approach that includes collaborative, continuous improvement aspects of Lesson Study and a simplified environment associated with micro. MLS is student-centered, knowledge-centered, assessment-centered, and partnership (community). It is a collaborative process involving four central components. It is based on the development, analysis and application of pre-service teachers working in small groups. In this respect, it is student-centered. With its knowledge-centered nature, the MLS supports the development of pre-service teachers' Content Knowledge and Pedagogical Content Knowledge. This knowledge is developed through the transfer of planning, execution, and reflection. It is evaluation centered with opportunities for feedback and revision. The instructor can evaluate the methods and observations of the pre-service teachers and give feedback. However, MLS group members are also able to criticize each other's methods and teachings and give feedback. The MLS is also partnership (community) centered, as it provides an opportunity for pre-service teachers to experience, make mistakes and criticize negatively by their peers and the instructor. In this respect, it can be said that MLS is a reform-based teaching (Fernández, 2005).

The MLS cycle begins with the course development phase. The second stage is the implementation stage. At this stage, the developed lesson is applied. After the application comes the analysis phase. At this stage, the data obtained from the applied course is evaluated and the final stage, the revision stage, is passed. During the revision phase, the course is re-evaluated in the light of data and feedback, and necessary adjustments are made. According to Fernández (2010), MLS groups should consist of a maximum of three person. What is ideal for these three-person groups is the selection of individuals with high, medium and low abilities in the subject and thus ensuring the heterogeneity of the group. Molina (2012) stated in the MLS that pre-service teachers mostly work in a small group consisting of three people with a supervisor at their head. He stated in the MLS, similar to the Lesson Study, that the advisor remained outside the teaching. Here, the role of the counselor is seen as a lecturer, course instructor or field expert. According to Fernández and Robinson (2006), the length of the lessons should be 30 minutes on average in the MLS. Similar to Lesson Study, there are stages of planning, implementation, analysis and revision. The instructor must be outside of the experience or the consultant must provide feedback and support as needed. Pre-service teachers are required to prepare a written reflective report at the end of the process. Unlike Lesson Study, the lessons must be recorded on video so that they can be watched again and feedback and corrections can be made.

The aim of this study is, therefore, to examine the effect of MLS experiences on the preservice teachers' development of subject specific TPACK skills for geometric objects. In order to determine TPACK levels of preservice teachers this research was conducted within the framework of this model. In line with this, the research question was formulated as: "What is the effect of MLS experiences on the development of preservice mathematics teachers' TPACK levels on curriculum and curricular materials and instructional strategies and representations for teaching with technologies component for geometric objects?"
The sub-problems are:

1) What is the effect of MLS experiences on the development of pre-service teachers' TPACK levels for geometric objects on curriculum and curricular materials component?
2) What is the effect of MLS experiences on the development of pre-service teachers' TPACK levels for geometric objects on instructional strategies and representations for teaching with technologies component?

## 3. METHODOLOGY

### *3.1. Research Method*

The present study was designed as qualitative research case study (Creswell, 2007). Yıldırım and Şimşek (2011), stated that qualitative case studies involve in-depth examination and analysis of one or more situations in terms of environment, individuals, events and processes. In addition, there is no generalization of the results in the case study, as in other types of qualitative research. However, the result obtained from each situation is an example for similar situations. Since measuring TPACK and its components is a tedious process, it should be examined in depth and in detail. It is known that TPACK is not only about using technology or technological materials during teaching and learning processes. It is necessary to add the technology into classroom practices in a way that aligns with the subject matter to be taught and pedagogical principles followed. For this reason, a case study was used in this study. Moreover, it is possible to evaluate pedagogical considerations such as how preservice teachers plan the lesson, how they sustain their lessons, and what they should avoid through the use of MLS. For this reason, MLS was utilized as a tool to develop preservice teachers' TPACK.

### *3.2. Participants*

The present study was carried out with the participation of third year preservice mathematics teachers studying at a public university located in the northeast of Turkey. Students successfully passed the technology-related courses such as Computer I and Computer II. In addition, they took pedagogical courses such as Instructional Technologies and Material Design, Instructional Methods, Techniques and Strategies. They also took content courses such as Analysis, Algebra and Geometry. The necessity of working with a heterogeneous group is emphasized in MLS (Fernández, 2010). For this reason, the heterogeneity of the participant group was ensured using criterion sampling strategy. The MLS group was formed taking into account students' grades (transcript records) and in line with that a student with a high Grade Point Average (GPA), and a low GPA, and an average GPA were selected. Pseudo names were used for the participants; Defne (who had a high GPA), Arya (who had an average GPA) and Alp (who had a low GPA). Defne and Arya were female students and Alp was a male student. Since the TPACK levels of Defne and Arya were similar, only the development of Defne and Alp are included in this study.

### *3.3. Data Collection Tools*

The data were collected through a Semi Structured Interview Form (SSIF), lesson plans prepared by preservice teachers, observation of micro-teaching activities, and follow up interviews after each data collection tool. The SSIF, which was used before and after MLS experiences, was prepared by revising the SSFI developed by the Karakuş, Aldemir & Tatar (2016) following three experts' opinions. The SSIF included both close-ended and open-ended questions. SSIF is designed for the four components and six levels of TPACK. In each component, there are statements that represent that component and show its level. In the form consisting of 24 expressions, preservice teachers are asked to choose the appropriate expression for that component and explain the reason by writing. Following each data collection point (i.e. SSIF, lesson plans, observation of micro teaching activities) interviews were held with the participants in order to obtain detailed data.

### *3.4. Study procedures*

The study procedures is presented in Figure 2

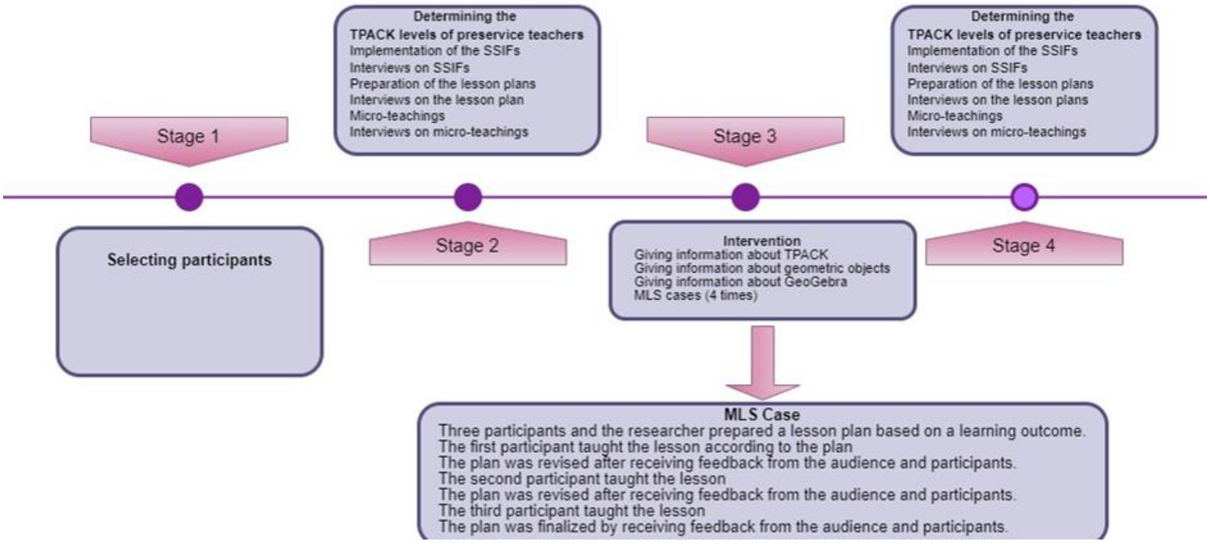


**Figure 2.** *Study Procedures*

In the first stage participants were selected. Then, in the second stage, TPACK levels of the participants were measured before MLS practice. The third stage was the intervention stage.

First, students were informed about the use of TPACK, geometric objects and GeoGebra 3D. Then, MLS applications were started. The aim of the MLS was to enable preservice teachers to blend content, pedagogy and technology knowledge through MLS experiences. MLS sessions were carried out four times. Each participant was interviewed a total of 12 times and 12 revised meetings were held. During the MLS cycle, firstly the MLS group members and one of the researchers had a meeting to decide on a learning outcome about geometric objects and prepared a lesson plan in line with the gain. The first participant performed a micro-teaching presentation to a group consisting of six peers. The other two participants and the researcher took notes as they observed the lesson. The presenters also received written feedback on the lesson from their peers. The MLS group members and the researcher discussed the micro-teaching practice of the first participant. The lesson plan was revised in accordance with the written comments by peers as well as the observation notes. Then the same process was repeated for the second and third participants. The lesson plan was finalized with the written feedback and observation notes from peers. Finally, after MLS experiences, TPACK levels of preservice teachers were re-determined. What was done in this final stage was the same as the pre-MLS stage.

### *3.5. Data Analysis*

The data were analysed using descriptive analysis techniques. The data collected from preservice teachers were coded in accordance with the TPACK development model for preservice mathematics teachers (Aldemir-Engin, Karakuş & Niess, 2022) and the consensus of three experts were sought to establish this framework. The data obtained from each data collection tool were coded following different categorizations for each tool. The SSIF developed by Karakuş, Aldemir & Tatar (2016) and adapted to the geometric objects by the researchers was analysed on TPACK development model for preservice mathematics teachers (Aldemir-Engin, Karakuş & Niess, 2022). The lesson plan template which was created to determine the TPACK levels of preservice teachers prepared by Aldemir, Karakuş & Tatar (2016) was used to code the lesson plans and post-plan interviews. The data collected from micro-teaching video recordings, post-micro-teaching interviews, and observation notes were analysed utilizing the observation schedule prepared by Aldemir &Karakuş (2017) and preservice teachers' TPACK levels were determined. The interviews conducted after each data collection tool was also analyzed with the method used in the analysis of the relevant data collection tool.

All of the four TPACK components as suggested by Niess (2013) were studied as part of the framework (i.e. An overarching conception of teaching science/ mathematics with technology, curriculum and curricular materials). However, the present study focused on the "Curriculum and curricular materials" and "Instructional strategies and representations for teaching with technologies" components. The reason for focusing on those two components were because; 1) the materials that the preservice teachers developed using the GeoGebra 3D software directly related to the "Curriculum and curricular materials" component and 2) the micro-teaching activities included pedagogical strategies that the preservice teachers made use of which is also directly related to the "Instructional strategies and representations for teaching with technologies" component.

## 4. FINDINGS

In this section, the effects of MLS experiences on the development of preservice mathematics teachers' TPACK for the subject of geometric objects are presented. This section is presented in two parts, namely, "The effect of MLS experiences on the development of pre-service teachers' TPACK levels for geometric objects on curriculum and curricular materials component" and "The effect of MLS experiences on the development of pre-service teachers' TPACK levels for geometric objects on instructional strategies and representations for teaching with technologies component". Both trainees' TPACK development was examined in terms of two of the four components of the framework presented in the introduction. These components are "Curriculum and curricular materials" (Curriculum) and "Instructional strategies and representations for teaching with technologies" (Teaching).

### *4.1. The Effect of MLS Experiences on the Development of Pre-Service Teachers' TPACK Levels for Geometric Objects on Curriculum Component*

In this section, the findings are presented on a level-based basis.

***Pre-recognizing Level:*** For this component, it is not known how technologies can be integrated into pre-recognition level mathematics curriculum topics. In the light of this data Defne's lesson plan, Alp's lesson plan and Defne's micro-teaching activity have been evaluated at this level Because before MLS, Defne prepared a lesson plan for "recognizing upright cone, determining its basic elements, and constructing and drawing opened cone". In the lesson plan, there is no expression of technology or any technological materials. She stated that she did not have any information about technology or preparing technological material on geometric objects in interview. Thus, it was determined that she was at pre-recognizing level. And also Alp prepared a lesson plan before MLS. In this plan, the gain he focused on was: "Recognize the vertical prisms, determine the basic features of the elements, constructs and draws the opening". In the "equipment to be used" part of the plan, he wrote a textbook, source books, ready-made tests, pencil, geometric formers, notebooks, colored pencils and a test book. There was no mention of technology or technological materials in the plan. In the interview after the plan, when asked why he didn't use technology, he said:

> "I only know GeoGebra as technology. But I don't know GeoGebra 3D for geometric objects. I did not use it because I thought the classroom environment was inappropriate. When everyone has a computer in the classroom, it is a nuisance when they turn to the extra pages. So I didn't choose to use" (interview after plan).

He is at the pre-recognizing level because he did not know any technology related to teaching geometric objects and therefore he did not include technology in the lesson plan. Before MLS, Defne undertook a micro-teaching activity to her peers which lasted 40 minutes according to her plan. She used concrete materials twice during the micro-teaching. She did not benefit from technology at all. After the micro-teaching, she was asked why she did not use technology. She stated that she did not know about the technologies or technological materials that could be used to teach about geometric objects. Therefore, she was considered to be at pre-recognizing level.

***Recognizing Level:*** One of the indicators of the recognizing level in this component is the thought that concrete material can be used instead of technology. He is also unsure of how to use technology in his curriculum. Before MLS, Alp undertook a micro-teaching activity for about 30 minutes. In his micro-teaching, he used concrete materials. He did not use this material effectively. He did not use technology at all. In the interview, on the other hand, he talked about the benefits of technology. He, however, explained that he was afraid to use it because he could not control the software completely. For this reason, he was considered to be at recognizing level.

***Accepting Level:*** Alp stated that technologies are motivating tools in teaching about certain geometric objects in the SSIF. However, it is difficult to incorporate technology into the teaching of many geometric objects in the curriculum. He also underlined this issue in the interview after the SSIF. It was observed that he was at accepting level for this component. Because in the curriculum component, a preservice teacher thinks that the use of technology in many subjects in mathematics is difficult, but technology in some specific subjects will motivate the students and the technology is used by the teacher.

***Adapting Level:*** In this component, technological materials are used as both teaching and learning (more teaching) tools at the adaptation level. In addition, technologies are mostly additional and sometimes complementary (complementary) tools in the mathematics curriculum. Before the MLS experience, Defne completed the SSIF and she stated that she thought technology activities were useful as complementary tools for geometric objects in the curriculum:

> "Technological activities are particularly useful for geometric objects. Students fully understand the subject with technology […] The technology is a complementary tool for the curriculum" (SSIF and interview).

Expressions used in the interview also support the findings from the SSIF. Therefore, it was determined that she was at adapting level. Following the MLS experience, she re-wrote a similar answer in the post-MLS SSIF:

> "Technology gives students the opportunity to study shapes in every way, because not every student can think in three dimensions. Thus, the technology and the curriculum complemented each other" (SSIF and interview). Therefore, her answer indicated that she was still in the adapting level.

Similarly after MLS Alp marked: "I think technology activities are useful as complementary tools in the geometric objects curriculum". He explained:

> "Geometric objects in two dimensional environments cannot be fully grasped. Comprehensible with technology. Take the cube. Normally, we knew one opening. But we've seen in practice that there are 11 openings. This is a shortcoming. But if we use technology, it will be complete" (SSIF and interview).

He was considered to be at the adapting level. Because a preservice teacher at the adapting level thinks that technologies are more supplementary and sometimes complementary tools in the mathematics curriculum.

After MLS, Defne prepared a new plan for the same gain. In the lesson plan, she stated that she would give the cone definition and then she would create a cone in GeoGebra 3D together with the students. She also wrote that she would show the opened and closed cone with the help of ready-made materials. She stated that she would give the cone and pyramid relation through the material she would prepare herself. There were statements that she would use technological materials in the lesson plan. She stated that she would use technology and technological materials as teaching and learning tools more focus on the teaching subject. However, it was observed that her use of technology in teaching about geometric objects increased in the revised plan. Thus, she was considered to be at adapting level.

After MLS, Defne did another 40-minute micro-teaching activity to her peers which focused on the same gain. She created a cone with her peers using GeoGebra 3D. With the help of technological materials, the cone was opened and closed. It was also presented that the cone was a special form of the pyramid thanks to the use of technological materials. In the post-micro-teaching interview, Defne stated that she used technology as an additional tool to support teaching. She said concrete materials could be damaged; however, technological materials were available for reuse. She explained that the lesson was teacher-centered and the students (her peers) used technological materials in the process. Nevertheless, she stated that she had guided the students with instructions and only used technology in her own way. It is seen that technological materials are used both as teaching and learning tools more focus on the teaching subject and more as complementary tools in mathematics curriculum. Because of this, she was considered to be at the adapting level.

***Exploring Level:*** After MLS Alp prepared a new lesson plan for the same gain. In the lesson plan, a computer, a smart board, a projection device, and GeoGebra 3D were mentioned in the "equipment to be used" part. Alp wrote that he would use ready-made materials and design materials with students. He stated that he would not directly explain the properties of objects, and that students would explore the properties of objects through materials. In the lesson plan, it was observed that he developed different materials with technology. He mentioned similar things during the interview. He was considered to be at exploring level.

Because there are expressions that technological materials are used both as teaching and learning tools more focus on the learning subject.

After MLS, Alp undertook a second micro-teaching activity for 45 minutes. This time, he used technological materials prepared with GeoGebra 3D. Those materials were both ready materials and were prepared with students. It was observed that the students were able to explore geometric objects. He used technological materials as a means of teaching and learning (more for learning). He also explored new ideas for to integrate technologies into the curriculum as problem solving tools. In addition to the materials prepared during the MLS process, it was found that Alp designed new materials. During the interview, Alp stated that his main aim was to explore the topic with the help of technology-enriched materials. Therefore, he was considered to be at exploring level.

***Advancing Level:*** No findings were found for this level in this section.

Defne's and Alp's TPACK level in terms of the curriculum component before and after MLS experiences are given in Table 1.

**Table 1.** *Defne's and Alp's TPACK Level for the Curriculum Component Before and After MLS.*

| | Defne's TPACK levels | | Alp's TPACK levels | |
|---|---|---|---|---|
| | Before MLS | After MLS | Before MLS | After MLS |
| SSIF and interview | Adapting (3) | Adapting (3) | Accepting (2) | Adapting (3) |
| Lesson plan and interview | Pre-recognizing (0) | Adapting (3) | Pre-recognizing (0) | Exploring (4) |
| Micro-teaching and interview | Pre-recognizing (0) | Adapting (3) | Recognizing (1) | Exploring (4) |

As seen in Table 1, Defne has reached the adapting level from pre-recognizing level in this component in the lesson plan and micro-teaching activities. In SSIF and interview, it remained at the adapting level. Alp showed an increase in this component in terms of all data collection tools. In MLS activities, studies such as creating technological materials for this component, using ready-made technological materials, and integrating technology into the geometric objects curriculum were carried out. In these studies, a joint plan was prepared with the pre-service teachers. Afterwards, teaching was carried out according to a common plan and revision meetings were held after each teaching. Accordingly, training was provided on the deficiencies of the pre-service teachers in using technological materials, the ways in which the students could use it, and the situation of combining materials with the content and pedagogy.

### *4.2. The Effect of MLS Experiences on the Development of Pre-Service Teachers' TPACK Levels for Geometric Objects on Teaching Component*

In this section, the findings are presented on a level-based basis.

***Pre-recognizing Level:*** In this component, it is not known how technologies at the pre-recognition level can be used for teaching purposes in mathematics lessons. The analysis of Defne's lesson plan before MLS, it can be seen that there was no expression regarding how technologies should be used for teaching in mathematics. In the interview, she also stated that she had no idea how to use the technologies that can be used in the subject for teaching purposes. Before MLS, Defne undertook a micro-teaching which lasted 40 minutes to her peers. She used the presentation method and the question and answer method. After explaining the subject, she asked questions. During the lesson, she did not benefit from the technology for any teaching purposes and, in fact, she did not use the technology at all. In the post-micro-teaching interview, she stated that she had no knowledge of how to use technology in order to teach the subject in a similar way to the lesson plan. Therefore, she was considered to be at the pre-recognizing level.

***Recognizing Level:*** After MLS, Defne marked:

> "Technology and geometric objects must be taught separately. First, learning should be supported by teacher-centered and teacher-oriented technology activities, and more complex and difficult concepts should be introduced or technology should be used firstly after the subjects of geometric objects are understood" (SSIF and interview).

Her explanations were fully supported by interview data. It was observed that Defne was at the recognizing level. This was because, at recognizing level, there are expressions that technology and mathematics should be taught separately, there are teacher-centered lessons and teacher guidance are needed, and technology should be used after the subjects are understood. Similarly before MLS according to Alp's lesson plan he wrote the questions and answers about subject. In his plan there was a section called teaching-learning methods and techniques. There was no statement about technology and of how technologies are used for teaching mathematics. It was revealed that he knew about the use of technology in mathematics lessons; however, he did not reflect this to the lesson plan. Therefore, he was considered to be at recognizing level. Before MLS he made more frequent use of the presentation, question and answer methods during the micro-teaching activity. After explaining the subject, he asked questions. During the lesson, he did not benefit from technology for teaching purposes and, in fact, he did not use the technology at all. In the interview, Alp explained that he knew about technology but he did not use it for teaching. For this reason, he was considered to be at recognizing level.

***Accepting Level:*** No findings were found for this level in this section.

***Adapting Level:*** In this component, the person explaining at the adapting level first needs to give direct information in technology activities with the presentation method (deductive). However, with technology, discovery, application and experimentation are made. Before the MLS experience, Defne completed the SSIF. She stated that she selected the option that the exploration of geometric objects by technology must be the main method and the lessons should be student-centered and she wrote the following into the text box regarding this question:

> "The teacher guides the students first and shows how to use the technology and how to draw the shape. The student acquires more lasting knowledge by creating his own shape. [...]First, the teacher must explain and show the subject. Students should create their own knowledge. In student-centered lessons, the student is kept in mind because of their own discovery. Therefore, the lessons should be student-centered"(SSIF and interview).

This statement is different than the answer selected in the SSIF since the option she selected in the SSIF indicated that she would be in the advancing level; however, the message given in the explanation above was considered to be at adapting level. Therefore, the answer to the interview held after the SSIF was examined to understand her level. It was determined from the dialogue that Defne was at the adapting level. This was because, in the interview, she, one more time, mentioned that the teacher had to explain firstly and then stated that the student should use technology. In the option selected in the SSIF, there was a situation for teaching the students under the control of the teacher. In addition, discoveries with technology were the main method for learning. In the explanation of the student, the teacher's lecture statement was passed. Therefore, it was determined that she was at the adapting level in this component. Before MLS, Alp completed the SSIF and stated that he thought the teacher first needs to provide direct information using technology-enriched activities and the method of presentation (deduction). Students should work with technology by following direct instructions and information. He used the same expressions in the interview. It was determined that Alp was at the adapting level. Because, at adapting level, the teacher gives direct information on the method of presentation (deduction) and technology activities. The students work with technology by following instructions and information directly. In the post-MLS SSIF, Alp selected the same answers and made similar statements. Therefore he was considered to have stayed at the adapting level.

***Exploring Level:*** After MLS Defne prepared a new plan for the same gain. In the plan, it was determined that the basic features of cone were determined with the use of technology together with peers, and the peers would make discovery with technology. Thus, she was considered to have reached exploring level. This is because, at exploring level, there are student-centered classes and technology-based activities. In class, both inductive and deductive methods are used and technology-assisted discoveries are made. After creating materials with technology, she designed activities to explore the main features through a discussion environment and the materials.

> "…I will not explain the basic features. I will ask students questions using GeoGebra 3D. I will make interpretations on the material, students will discover features"(interview after plan).

When Defne's answers to the interview questions were examined, she was identified to be at exploring level.

After MLS, Defne made micro-teaching to her peers. It was observed that in her micro-teaching, she integrated technology and she utilized student-centered activities with the participation of peers. In addition, it was also observed that she overcame the difficulties arising whilst undertaking technology-integrated activities. However, she used multiple teaching strategies with technology. It was observed that the group was stimulated through questions rather than focusing on information transfer. Therefore, she was considered to have reached the exploring level.

After MLS, in the method part of his plan, Alp included expressions such as; ways of invention, technology supported mathematics education. In the lesson plan, there was a statement that technology and student-centered activities will be carried out and technology and multi-teaching strategies (both inductive and deductive) will be used. In addition, there was an expression that the group they described would make discoveries with technology, and that the teacher was a guide in the use of technology and actively involved the students. Therefore, he was considered to have reached exploring level. After MLS, Alp undertook a second micro –teaching activity based on his revised plan. In that new lesson, he integrated technology into the content with the participation of peers in planning, implementation and reflection during teaching and learning processes. He created student-centered activities with technology and minimized the extent of difficulties in technology-enriched activities (i.g technological problems about software, difficulties in using the software, difficulties in creating objects with software). He was dominated technology in his micro- teaching activity. He helped his peers in using the technology as a guide. It showed practical ways to use the software. He focused on understanding mathematics by guiding his peers in the use of technology. He used multiple teaching strategies (both induction and deduction) with technology and his peers made discoveries with technology and reinforced the topic. Peers were actively involved in that process through questions rather than knowledge transfer. Therefore, he was considered to have moved to exploring level.

***Advancing Level:*** No findings were found for this level in this section.

Defne's and Alp's TPACK level in terms of the teaching component regarding before and after MLS experiences is provided in Table 2.

**Table 2.** *Defne's and Alp's TPACK Level for the Teaching Component Before and After MLS.*

| | Defne's TPACK levels | | Alp's TPACK levels | |
|---|---|---|---|---|
| | Before MLS | After MLS | Before MLS | After MLS |
| SSIF and interview | Adapting (3) | Recognizing (1) | Adapting (3) | Adapting (3) |
| Lesson plan and interview | Pre-recognizing (0) | Exploring (4) | Recognizing (1) | Exploring (4) |
| Micro-teaching and interview | Pre-recognizing (0) | Exploring (4) | Recognizing (1) | Exploring (4) |

As can be seen from Table 2, both Defne and Alp had an increase in TPACK levels in terms of lesson plan and micro-teaching. In MLS activities, situations such as teaching methods with technology, enabling students to explore and experiment, and the integration of technology into the method were discussed for this component. In addition, situations such as minimizing the difficulties and performing teacher- and student-centered activities were also discussed.

## 5. RESULTS AND DISCUSSION

In this study, it was aimed to improve the TPACKs of pre-service mathematics teachers on geometric objects with the MLS method. Following MLS experiences, it was observed that Alp's TPACK level increase was higher than Defne. His lesson plan and micro teaching levels were up to 4th level in both TPACK components. It is possible that this difference can be related to having the experience of using GeoGebra prior to the study. In this sense, Alp may have developed more since he had used this technology in the past and was more experienced. As a result, it was considered that MLS experiences had a positive effect on pre-service teachers' TPACK development.

Qualitative studies are usually conducted with a small group to determine the impact of MLS on TPACK. In these studies, analysis of the lesson plan, reflective diaries, interviews, TPACK questionnaires were used (Zhang & Tang, 2021). When the pre-intervention findings of the participants were examined in the study, it was determined that the SSIF TPACK levels were higher than the lesson plans and micro-teaching. This fact shows that only data collection tools cannot give accurate information in determining TPACK. So, in this study, it was aimed to obtain detailed information by using multiple measurement tools. In addition, a qualitative study was designed with few participants. When Balgalmış, Çakıroğlu & Shafer (2014) and Saralar, Işıksal-Bostan & Akyüz (2018) researches were examined, it was seen that a model (Niess, 2009) was studied and development was observed. Similarly, in this research, a model was studied and development was observed. Kartal and Çınar (2021) used the Mudzimiri (2012) rubric while examining the development of TPACK on polygons. This rubric also includes four components and five levels. Similar to this research, as a result of other researches, it was determined that MLS applications contributed to the development of TPACK (Balgalmış, Çakıroğlu & Shafer, 2014; Birel & Çakıroğlu, 2018; Cavin, 2007; Dağ

& Temur, 2018; Danday, 2019; Kartal & Çınar, 2021; Saralar, Işıksal-Bostan & Akyüz, 2018).

In this research, a dynamic software, GeoGebra, was used to develop pre-service teachers' TPACKs. In the literature, there are studies in which GeoGebra is used to develop pre-service teachers' TPACKs, either with the help of a model or in terms of seven components. In this respect, the research followed a similar process with the literature (Açıkgül & Aslaner, 2023; Akkoç, 2022, Assadi & Hibi, 2020; Bretscher, 2022; Kartal & Çınar, 2022; Morales-López, Chacón-Camacho & Vargas-Delgado, 2021; Za'ba, Ismail, Abdullah, 2020). In the research, it has been determined that the integration of technology, pedagogy and the content of the participants is slow. For example, in the first MLS applications, it was determined that the participants had difficulties in using GeoGebra and focused more on it. Kasti & Lavizca (2021) mentioned that the process of developing TPACK with GeoGebra is slow. Bueno, Lieban & Ballejo (2021) also stated that the participants progress slowly and they are more careful in combining technology, pedagogy and content in the process.

## 6. RECOMMENDATIONS

In terms of the limitations of the study, only geometric objects are discussed in this study. It may be appropriate to be able to study different subjects on mathematics. It is important and necessary to involve pre-service teachers in MLS environments so that they can be part of the learning community and learn more from experts and collaborative work (Elbehary, 2020). In this study, only one MLS group was studied. Designing studies with more than one group can be presented to the researchers as suggestions. When working with more than one group, a comparison between groups can be made. Also working with more groups will increase the experience more than the initial situation (Kartal & Çınar, 2021). In addition, in this study, MLS groups did not teach students but their peers. In this case, it is not possible to make a clear conclusion that the same performance can be observed in real learning environments (Perkmen & Pamuk, 2011). In this research, only GeoGebra 3D was used as technology. The use of different technologies can be presented as a suggestion.

When the findings of the study were examined, it was found that participants' TPACK levels did not reach the highest level possible. Initially, this could be interpreted as a drawback of the study. Following four MLS sessions, the question of why there was no evidence indicating the level of advancing can be asked. However, even in Niess (2009) study, who worked with teachers on a regular basis, there were no teachers who were considered to have reached the advancing level. It is possible that such a level can be reached only after long-lasting training and education for preservice teachers.

The inclusion of technology and TPACK in our curriculum also brings about the formation of different lessons. It is thought that pre-service teachers should take technology-related lessons for mathematics and be asked to design technological materials. Moreover, TPACK-related courses should be integrated into teacher education programmes. In this way, pre-service teachers will have the opportunity to combine the content, pedagogy and technology lessons that they take during their undergraduate education.

## 7. ABOUT THE AUTHORS

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