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2024

THE DEVELOPMENT OF AN ICT-INTEGRATED GUIDELINE FOR HIGH SCHOOL 3D GEOMETRY LESSONS BASED ON THE PERCEPTIONS OF PRE-SERVICE TEACHERS AND THEIR INSTRUCTORS

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A THESIS SUBMITTED

FOR

THE DEGREE OF MASTER OF ARTS

IN

CURRICULUM AND INSTRUCTION

İHSAN DOĞRAMACI BİLKENT UNİVERSİTY

ANKARA

JULY 2024

This thesis

is dedicated to

my family for their endless love and support.

The Development of an ICT-Integrated Guideline for High School 3D Geometry Lessons Based on the Perceptions of Pre-Service Teachers and Their Instructors

The Graduate School of Education
of
İhsan Doğramacı Bilkent University

by

Alisa Sümeyye Uymaz

In Partial Fulfilment of the Requirements for the Degree of
Master of Arts
in
Curriculum and Instruction

Ankara

July 2024

İHSAN DOĞRAMACI BILKENT UNIVERSITY
GRADUATE SCHOOL OF EDUCATION

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Alisa Sümeyye Uymaz

July 2024

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Arts in Curriculum & Instruction.

Asst. Prof. Dr. Anita Alexander (Advisor)

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Arts in Curriculum & Instruction.

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ABSTRACT

The Development of an ICT-Integrated Guideline for High School 3D Geometry Lessons Based on the Perceptions of Pre-service Teachers and Their Instructors

Alisa Sümeyye Uymaz

MA in Curriculum and Instruction

Advisor: Asst. Prof. Dr. Anita Alexander

July 2024

Information and Communications Technology (ICT) involves a collection of technologies used for information processing, communication, and distribution. In education, the use of ICT technologies has several benefits. Especially, in mathematics, ICT tools improve problem-solving abilities, increase student engagement, and help to visualize abstract concepts. The primary aim of this study was to explore how pre-service mathematics teachers' perceptions in regard to effectiveness and challenges of using ICT tools in 3D Geometry lessons vary across different universities. The secondary purpose of the study was to investigate how sufficient are the Instructional Technology and Material Development courses at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons. Lastly, the study aimed to identify how instructors at different universities perceive and integrate ICT tools, and what are the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools.

Keywords: *Information and Communication Technology (ICT), GeoGebra, High school 3D Geometry lessons*

ÖZET

Öğretmen Adayları ve Eğitmenlerinin Algılarına Dayalı Lise 3 Boyutlu Geometri Dersleri için BİT Entegreli Klavuz Geliştirilmesi

Alisa Sümeyye Uymaz

Eğitim Programları ve Öğretim Yüksek Lisans Programı

Danışmanı: Dr. Öğr. Üyesi Anita Alexander

Temmuz 2024

Bilgi ve İletişim Teknolojisi (BİT), bilgi işleme, iletişim, depolama ve dağıtım için kullanılan teknolojilerin bir koleksiyonunu içerir. Eğitimde BİT teknolojilerinin kullanımının birçok faydası vardır. Özellikle matematikte BİT araçları problem çözme becerilerini geliştirmekte, öğrenci katılımını arttırmakta ve soyut kavramların görselleştirilmesine yardımcı olmaktadır. Bu çalışmanın temel amacı, matematik öğretmeni adaylarının 3D Geometri derslerinde BİT araçlarını kullanmanın etkililiği ve zorluklarına ilişkin algılarının farklı üniversiteler arasında nasıl değiştiğini araştırmaktır. Araştırmanın ikinci amacı ise farklı üniversitelerdeki Öğretim Teknolojileri ve Materyal Geliştirme derslerinin matematik öğretmeni adaylarını 3D Geometri derslerine BİT araçlarını etkili bir şekilde entegre etmeye hazırlamada ne kadar yeterli olduğunu araştırmaktır. Son olarak, çalışma farklı üniversitelerdeki öğretim elemanlarının BİT araçlarını nasıl algılayıp entegre ettiklerini ve öğretmen adaylarının bu araçları kullanma konusundaki yeterliliklerini geliştirmek için algılanan yararların, zorlukların ve etkili stratejilerin neler olduğunu belirlemektedir.

Anahtar kelimeler: *Bilgi ve İletişim Teknolojileri (BİT), GeoGebra, Lise 3 boyutlu Geometri dersleri*

ACKNOWLEDGEMENTS

First of all, I would like to express my deepest appreciation to my thesis advisor Asst. Prof. Dr. Anita Alexander for her valuable guidance, endless support, and patience throughout this academic journey. Her gentle encouragement and invaluable feedback have filled my academic skills and inspired me along the way.

Secondly, I am very grateful to the faculty members at Bilkent University Graduate School of Education for their experiences, academic rigor, and support throughout the program.

I owe special thanks to my mother Firdevs, who has always been there for me and my father Şükrü, who supported me throughout my life. Also, I would like to thank my dear brother Talha Nuh, my lovely sister Feyza, and my grandmother Meryem for their pure love and support.

Lastly, I would like to extend my gratitude to my dear friends and students who encouraged me during this challenging academic endeavor with their love and support. Their presence has added brightness and enjoyment to every moment, whether it has been late-night study sessions or brainstorming discussions, reminding me that I am never alone on this road.

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CHAPTER 1: INTRODUCTION

Introduction

In recent years, technology has become an essential part of education. Technology-based education offers new opportunities for students to create content, visualize mathematical objects, and engage in the discovery of critical concepts through appropriate applications (Abramovich & Connell, 2014). Additionally, Pedersen et al. (2021) stated that the usage of digital technologies has a huge impact on representation competency. Representation is a combination of signs, characters, diagrams, objects, pictures or graphs, which teachers can use for an effective mathematics course with the help of technological tools. In addition to assisting students in creating their own visual representations of mathematical ideas and concepts, the use of technology in mathematics education also allows students to explore several branches of mathematics, including geometry, algebra, and statistics (National Council of Teachers of Mathematics [NCTM], 2000).

This study aimed to explore how pre-service secondary school mathematics teachers' perceptions vary across different universities with regard to the effectiveness, benefits, and challenges of using Information and Communication Technologies (ICT) in 3D Geometry lessons. Also, the current study investigated how sufficient the Instructional Technology and Material Development courses are at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons. The target population of this research was the pre-service mathematics teachers and their instructors of the Mathematics Education faculties in the top-ranking universities in Türkiye based on Yüksek

Öğretim Kurulu (YÖK), which translates to Council of Higher Education (YÖK, 2023). Lastly, the study aimed to identify how instructors at different universities perceive and integrate ICT tools, and what are the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools. According to the suggestions of the instructors and pre-service teachers, an ICT-integrated guideline for Prisms was developed to provide an example of a well-developed guideline for high school mathematics lessons.

Background

Technology has become a necessary part of our daily lives in many areas such as education, industry, and media. Computers, the Internet, and other associated technologies (e.g., ICT) are becoming increasingly prevalent in workplaces for both the current and next generation (Sharma et al., 2011). Researchers reported that ICT allows companies to be more efficient, effective, and responsive to the requirements of the consumers (Jameel et al., 2017). In 2015, Lewin and McNicol mentioned that the usage of ICT tools supports the development of 21st century skills, in particular digital literacy, critical thinking, creativity, communication, and collaboration skills.

Although technology has an important role in many areas in our daily lives, the field of education may be one the most essential areas to integrate the technological tools. Technology holds an important place in education and provides many opportunities for both teachers and students. According to Das (2019), using ICT tools in education improves the learning process through the visualization of interactive educational materials. Similarly, Duma and Monda (2013) concluded that the communication skills of students can be improved through the use of ICT tools. Also, it enables students to study effectively and access information faster. In 2017, Hernandez showed that ICTs have positive contributions to education and society, and Higgins et al. (2019) highlighted that technology has a significant impact on student achievement, motivation, and attitudes.

In particular, there are many studies on the benefits of using technological tools in mathematics education (Appavoo, 2020; Birgin & Uzun, 2021; Granberg & Olsson, 2015). These studies investigated that mathematics achievement could be accounted for by using technology, and ICT teaching and learning tools have a positive effect on the mathematics achievement of K-12 students. Notably, other studies concluded that technology-based education in mathematics teaching is more effective than traditional methods of instruction (Çavuş & Deniz, 2021). ICT enables students to enhance the learning process and visualize concepts by providing additional opportunities to see and interact with mathematical concepts.

According to the principles advocated by NCTM (2000), the usage of ICT tools empowers students to participate in inquiry-based learning, investigate mathematical concepts, and develop critical thinking skills necessary for success in today's digital world. Based on Shulman's (1986) framework, Mishra and Koehler (2006) created a movement known as Technological Pedagogical Content Knowledge (TPACK) that supports teachers to integrate TPACK components: Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK). Since TPACK provides a robust model for understanding the complexities of integrating technology into teaching, it is used as a conceptual framework in this study.

Similarly, the effective usage of ICT teaching and learning tools in mathematics education has been specifically emphasized by the Ministry of National Education (MoNE) in Türkiye. The latest curricular changes in documents in mathematics education have particularly recommended mathematics teachers to adopt ICT teaching and learning tools such as Dynamic Geometry Software (DGS), Graphic Display Calculator (GDC), and other related tools (MoNE, 2018).

Given this emphasis of ICT in Turkish mathematics education, Aydos (2015) mentioned that there is a need for Turkish mathematics teachers to learn how to use ICT tools effectively. This finding is especially important in light of other studies that have revealed that mathematics teachers in Türkiye are facing various challenges such as the lack of technological understanding, inadequate ICT training and learning opportunities, and limited technical assistance (Gulbahar & Guven, 2008; Unal & Ozturk, 2012). Aslan and Zhu (2015) identified that some pre-service teachers are concerned about using ICT tools because of the difficulty, time consumption, and possible misuse. Akbaba-Altun (2006) indicated that in-service training courses for mathematics teachers are insufficient and have a lack of hands-on activities for specific subjects. She also mentioned that supervisors, school administrators, computer coordinators, and teachers in Türkiye need well-planned and up-to-date training programs and guidelines for using ICT teaching and learning tools in classrooms.

Several large-scale projects have been developed to encourage the use of ICT tools in Türkiye, the most essential of which being the FATIH (Fırsatları Artırma ve Teknolojiyi İyileştirme Hareketi) project, which translates to the Movement of Increasing Opportunities and Improving Technology. In 2010, MoNE started the FATIH project in over 50 schools to provide boards, projectors, and internet access, and to deliver in-service training for teachers (MoNE, 2012). However, most of the teachers claimed that the project did not work because of the lack of information about using ICT teaching and learning tools (Çiftçi et al., 2013).

Problem

Technology is becoming one of the most essential aspects of mathematics education. According to the mathematics curriculum published by MoNE (2018) in Türkiye, teachers are expected to use ICT tools, DGS, and GDC effectively. MoNE (2018) lists digital competencies as an essential part of the curriculum, safe and critical use of ICT tools for business, daily life, and communication. The ability to use technology is strengthened by fundamental skills such as utilizing computers to retrieve and assess data, creating and sharing information, and communicating with others through the Internet. However, studies showed that the traditional approaches on teachers' practices, teachers' attitudes and beliefs, teachers' perceptions of their lack of knowledge and skills, and inadequacies regarding in-service teacher training are main obstacles faced by teachers (Demiraslan & Usluel, 2008; Unal & Ozturk, 2012). Moreover, Ghavifekr et al. (2016) concluded that limited technical support, lack of effective training, and lack of teachers' competency are the challenges related to ICT use in teaching and learning.

More specifically, GeoGebra is one of the most useful DGS that enables students to enhance the learning process and visualize concepts by providing additional opportunities to see and interact with mathematical concepts. Uwurukundo et al. (2022) concluded that GeoGebra has a significant effect on secondary school students' achievement in 3-D Geometry. Another study revealed that using ICT tools such as GeoGebra improves the learners' performance in Geometry (Adelabu et al., 2019). However, there is a gap in the literature on how to use ICT teaching and learning tools in mathematics education in Türkiye, particularly in 3-D Geometry. Although important steps have been taken to encourage ICT usage, most of the mathematics teachers in Türkiye are not using or rarely using ICT devices in their classrooms (Unal & Ozturk, 2012).

Purpose

Are the pre-service mathematics teachers in Türkiye competent enough to use technological tools in their future classroom effectively with regard to active learning? The primary aim of this mixed methods study was to explore how pre-service mathematics teachers' perceptions with regard to effectiveness, benefits, and challenges of using ICT tools in 3D Geometry lessons vary across different universities. The secondary purpose was to investigate how sufficient the Instructional Technology and Material Development courses are at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons. Lastly, the study aimed to identify how instructors at different universities perceive and integrate ICT tools, and what are the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools.

The study began by interviewing instructors of pre-service mathematics teachers to investigate the perceived benefits, challenges, and effective strategies to prepare future teachers to use ICT tools in their lessons. In addition, instructors were asked to share what is needed to improve the quality of Instructional Technology and Material Development courses. For the pre-service teachers, an online survey was administered to learn their perceptions in regard to effectiveness and challenges of using ICT tools in 3D Geometry lessons. They were asked about their concerns and how competent they feel to develop technology integrated lessons.

As with their instructors, pre-service teachers were asked to share their suggestions for an ICT-integrated guideline that would support their willingness and ability to use ICT tools. Based on the suggestions of the instructors and their students, an outcome of this study will be to develop an ICT-integrated guideline for Prisms that the instructors of Instructional Technology and Material Development courses can share with pre-service teachers to provide an example of effective integration of technology and offer several technology-based activities.

Research Questions

The following are the main research questions investigated according to the purposes of the study:

1. How do pre-service secondary school mathematics teachers' perceptions of the effectiveness and challenges of using ICT tools in 3D Geometry lessons vary across different universities?
2. How sufficient are the Instructional Technology and Material Development courses at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons?
3. How do instructors at different universities perceive and integrate ICT tools in 3D Geometry lessons, and what are the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools?

Significance

Although there are several projects developed to encourage the use of ICT tools in Türkiye, teachers do not have sufficient competencies to use ICT tools in their lessons (Çiftçi et al., 2013). Since there is a lack of knowledge about ICT usage, this study will contribute to the literature in terms of increasing usage of ICT tools in mathematics education. Dockendorff and Solar (2018) emphasized that many teachers are not prepared to integrate new digital technologies into mathematics lessons. This study will provide a guideline for pre-service mathematics teachers, in-service teachers, and administrators to adopt the technology usage and increase their awareness to integrate technology into mathematics lessons.

Since there is a positive correlation between technology training in education faculties and the teachers' integration of technology into pedagogy (Georgina & Hosford, 2009), this study is significant in terms of cultivating mathematics teachers who are aware of the benefits of technology integration, and to try to be up to date in an ever-changing world. Lastly, this study will contribute to the curriculum developers and the instructors of Instructional Technology and Material Development courses in mathematics education departments in Türkiye by providing them with evidence on the ICT usage of pre-service teachers and their needs.

Definition of Key Terms

Dynamic Geometry Software: A type of software that helps teachers and students educate and learn the relationships between geometrical behaviors and forms (Aktümen et al., 2011).

Information and Communications Technology: A diverse set of technologies used for information processing, communication, storage, and dissemination, playing a crucial role in modern society for various purposes.

National Council of Teachers of Mathematics: A professional organization dedicated to support and promote high-quality mathematics education for all students and teachers.

The Ministry of National Education: Official authority in Türkiye that controls and permits the establishment of all educational institutions from pre-school to the conclusion of the 12th grade, creates their curriculum, and includes all types of services in education and training programs.

GeoGebra: A free and user-friendly mathematics program that combines DGS and CAS capabilities and has been translated into over 40 languages. From primary school through university, the program may be used. GeoGebra combines geometry, algebra, spreadsheets, graphing, statistics, and calculus.

Technological Pedagogical Content Knowledge: A framework that emphasizes the knowledge and skills teachers need to effectively integrate technology into their lessons. It clarifies three types of knowledge: technological knowledge, pedagogical knowledge, and content knowledge.

CHAPTER 2: REVIEW OF RELATED LITERATURE

Introduction

The purpose of this chapter is to review the literature comprehensively on the usage of ICT teaching and learning tools in mathematics education. Firstly, the effects of using ICT tools in mathematics education are discussed and the concerns of teachers are mentioned. Then, DGS, GeoGebra is introduced to give more insight on the usage of the DGS and the opportunities it provides. Afterwards, the history of three-dimensional Geometry is examined, and the objectives of MoNE in Türkiye are compared with the standards of NCTM for high school 3D Geometry topics (e.g., right prism, right pyramids, right circular cylinder, right circular cone, sphere).

Later on, the critical role of implementation techniques of ICT tools and teacher training programs in improving the teaching and learning experience in Turkish High School Mathematics classes is discussed. Also, Instructional Technology and Material Development courses, where pre-service mathematics teachers learn about ICT tools in mathematics education faculties in Türkiye are examined. In the last section, TPACK is presented as the conceptual framework that underpins the study.

ICT Usage in Mathematics Education

The use of ICT teaching and learning tools has become increasingly popular in primary and secondary schools over the past few decades. Das (2019) highlighted the importance of ICT usage in mathematics education, which allowed mathematics to enter the field of technology and industry after being reduced to the purely academic domain for a long time. “Based on selected literature, it was found that the advantages of applying ICT in teaching mathematics are that it attracts students' interest in learning mathematics; it increases their motivation and performances; it encourages lifelong learning; and it facilitates positive interactions and relationships" (Zakaria & Khalid, 2016, p. 1537). The availability and increased access to technology in mathematics education have led to new perspectives on student learning development.

Many teachers, educators, and researchers believe that this technological advancement presents opportunities for change in mathematics education and could lead to better student learning outcomes (Drijvers et al., 2016). Incorporating a technology-enhanced lesson, which can be a valuable supplement to traditional teaching methods on a weekly basis, enhances students' academic performance (Ran et al., 2021; Skryabin et al., 2015). Furthermore, Li and Ma (2010) highlighted the importance of ICT tools in motivating students and increasing their mathematics achievement.

According to NCTM (2012), involving students in mathematically suitable tasks and explorations that demand active participation and utilizing technology designed for mathematics has a huge impact on student learning. Similarly, Turkish policy makers have been promoting the integration of technology in mathematics classrooms among teachers. MoNE in Türkiye (MoNET, 2018) emphasized the importance of using ICT teaching and learning tools in mathematics.

In 2018, curricular changes in documents and mathematics sources emphasized the use of technology in teaching and learning mathematics. The MoNE curriculum includes the suggested use of DGS, graphing software, and other technology tools to provide new learning opportunities and to promote creative thinking. The MoNE also expects students to use these technologies effectively, with the goal of exploring mathematical concepts and developing different types of thinking skills. Accordingly, using ICT can help students to work on real-life mathematical problems and spend more time on reasoning and creative thinking.

In line with the recommendations put forth by influential policy-making organizations, some research conducted in Türkiye has supported the use of technology in mathematics. Aypay (2010) suggested enhancing the Turkish educational system by integrating technology into course materials. He also mentioned that students' access to computers in Türkiye was limited with a higher number of students per computer compared to academically higher performing countries, according to PISA 2003 results. Moreover, Delen and Bulut (2011) found that students' knowledge of and experience with technology played an important role in the differences in math and science achievement between individuals and schools. Therefore, when creating classroom environments, ICT should be considered as an important factor (Delen & Bulut, 2011).

Additionally, Eyyam and Yaratan (2014) concluded that students have a positive attitude towards utilizing technology in mathematics lessons. In 2012, The Turkish MoNE created the FATIH project, with the aim of enhancing the use of technology in education. This was done by providing technological tools such as tablet computers and interactive whiteboards. Çevikbaş and Çevikbaş (2015) showed that pre-service mathematics teachers recognized the project as a significant educational reform movement. However, the participants also expressed doubt that the project could accomplish its objectives.

In 2013, Pamuk et al. concluded that although many teachers and students have a positive attitude towards having access to tablets and interactive white boards, several challenges and problems were determined such as limited access to e-content and e-materials, lack of interactivity between interactive boards and tablets, and a sensitivity problem with the touch screen. On the other hand, the researchers also mentioned that the integration of technological tools into education increased communication and collaboration in the classroom with more joyful audio-visual lessons, which was an essential consequence of the project.

Many studies revealed that teachers have a positive attitude towards the use of ICT tools in mathematics, but they do not have sufficient knowledge and experience on the usage of ICT teaching and learning tools. For example, Dhakal (2018) mentioned that mathematics teachers are willing to use ICT tools both for their professional development and to enhance students' performance. Correspondingly, Appavoo (2020) concluded that secondary mathematics teachers are optimistic about the pedagogical value of ICT and are willing to incorporate technology into the teaching and learning process. Also, pre-service teachers suggested including mathematics teaching and learning ICTs in the curricula of teacher education as early as possible (Ndlovu et al., 2020).

Despite their positive attitudes towards ICT usage in mathematics classes, many teachers have concerns like losing control of the class while trying to use ICT tools, consuming too much time and not being able to "complete" the syllabus, and being unable to integrate technological tools because of a lack of specific teaching skills (Appavoo, 2020). Similarly, a study conducted by Keong et al. (2005) identified six major challenges that mathematics teachers are facing while using ICT tools: limited time allocated in the school schedule for ICT projects; inadequate opportunities for teacher training in ICT; insufficient technical support for such projects; limited understanding of strategies to effectively integrate ICT into the curriculum; challenges in integrating and utilizing various ICT tools within a single lesson; and a lack of resources at home for students to access required educational materials. In this regard, Keong et al. (2005) proposed an e-portal, consisting of a resource repository and a lesson planner, to fulfill the needs of mathematics teachers while using ICT tools.

There are several advantages of using ICT tools in mathematics education, such as enhanced problem-solving skills, increased student engagement, and visualization of abstract concepts. To enhance the success of ICT integration in the classroom, teachers need to have targeted assistance and planned implementation strategies. Although there are many proposals and suggestions on the usage of ICT tools in mathematics courses, still there is a gap in the ICT usage among the teachers.

Dynamic Geometry Software: GeoGebra

Dynamic Geometry Software (DGS) refers to computer software created to facilitate the exploration and construction of geometric concepts in an interactive and dynamic setting. DGS promotes a greater understanding of geometric relationships and qualities by enabling users to modify, transform, and study geometric objects in real-time (Kortenkamp, 1999). It supports exploratory learning by providing users with opportunities to investigate geometric properties, construct conjectures, and test hypotheses through hands-on experimentation. It also enables users to investigate relationships between geometry and other mathematical fields by integrating algebraic and calculus tools. GeoGebra, Cabri Geometry, Geometer’s Sketchpad etc. are the most common examples of DGS; however, GeoGebra will be the focus of DGS tools in this study.

GeoGebra, which is available as a web application, desktop software (Windows, macOS, Linux), and mobile app (iOS, Android), is a free, open-source

DGS with dynamic capabilities created by Markus Hohenwarter in 2002 for his master's thesis project and has now been translated into more than 70 languages (GeoGebra, 2024). It facilitates the teaching and learning of mathematics by providing a comprehensive software environment that offers a dynamic interface with graphing, algebra, geometry, and other features. This software was designed to combine the aspects of computer algebra systems (e.g., Derive, Maple) with DGS like Cabri Geometry and Geometer's Sketchpad (Hohenwarter et al., 2009). It provides an interactive approach to learning and teaching mathematics, enabling students to visually investigate mathematical concepts and acquire a deeper understanding of subjects (Radović et al., 2020).

GeoGebra is a strong software application in geometry with dedicated tools for constructing geometric figures, exploring transformations, and working with dynamic geometry. Users can create 2D and 3D graphs, which can be manipulated in real-time to better understand mathematical concepts. In addition, it provides a platform for creating and sharing interactive materials, where educators can create applets, worksheets, and books to enhance their lessons.

The use of GeoGebra is also consistent with the pedagogical theory of constructivism, which proposes that learning is an active process where individuals construct their knowledge and comprehension (Bodner, 1986). Sarita (2017) concluded that constructivism emphasizes student-centered learning and encourages teachers to reflect on their practices. GeoGebra offers personalized student-centered learning experiences where students can explore areas of interest at their own pace and receive immediate feedback on their actions. Also, it allows teachers to create scaffolding using interactive applets, guided questions, and well-planned activities. GeoGebra also offers an interactive platform by encouraging students to investigate, manipulate, and construct mathematical knowledge through interactions with mathematical concepts. In 2019, Bwalya used multiple representations theory (Bruner, 1966) and social constructivism (Vygotsky, 1978) as a framework to investigate how GeoGebra affected students' performance in geometric transformations and their attitudes about using technology to learn mathematics. The researcher concluded that GeoGebra is an effective tool for both male and female students in learning geometric transformations, in line with the constructivist theory.

The integration of GeoGebra software into various educational levels in terms of the teaching and learning process is becoming more prevalent, as it supports the enhancement of mathematical competencies throughout the learning process (Arteaga-Valdés et al., 2019). According to Wassie and Zergaw (2019), GeoGebra has several advantages, including the facilitation of both individual and group learning, promotion of creativity, support for autonomous learning, provision of a free access tool, and compatibility across multiple platforms. Also, Wassie and Zergaw (2019) concluded that GeoGebra enables the creation of dynamic scenes, permits the saving and exporting of files in various output formats, and fosters an international community that shares educational materials as a means of support. Similarly, it enables students to concentrate on the methodologies involved in modeling a problem and analyzing its solutions. Many studies revealed that GeoGebra software significantly enhances students' mathematical conceptual understanding and mathematical competencies, particularly in understanding, geometric reasoning, and problem-solving (Baye et al., 2021; Celen, 2020; Muñante-Toledo et al., 2021; Widyawati et al., 2021; Zengin et al., 2012; Zulnaidi & Zamri, 2017).

In 2015, Wah concluded that creating an engaging and pleasurable learning environment with GeoGebra has a significant impact on students' motivation in the acquisition of mathematical knowledge. Especially in Geometry, which becomes a difficult subject for students as it involves abstract concepts such as geometric constructions, coordinate geometry, conic sections, and three-dimensional figures, using more tangible learning tools such as GeoGebra helps students to understand the concepts of geometry better (Widada et al., 2021). Another study conducted by Doğan and İçel (2011) investigated potential impacts of GeoGebra-based activities on students' performances in triangles, especially Pythagoras relations. The researchers performed an experimental study where students in the experimental group took a planned course with GeoGebra constructed activities for two weeks, while the control group continued their traditional teaching and learning procedure. According to the results, the experimental group was more successful than the control group. Also, the results indicated that GeoGebra enhances students' motivation as well as their learning and achievement.

Similarly, Martinez (2017) designed a quasi-experimental study to determine whether GeoGebra has a positive influence on high school students' achievement in Geometry. The researcher analyzed two classes from a high school located in a rural area in Central California for five weeks, where in the experimental group students were taught with GeoGebra and the control group continued their traditional education. The results showed that students learn the High School Geometry standards more effectively when using GeoGebra as a hands-on learning tool during their lessons. Furthermore, GeoGebra provides educational games that improve students' mathematical understanding. Septian and Monariska (2021) also concluded that GeoGebra-based game education has a positive impact on students' learning motivation as well as their mathematical conceptual understanding.

In addition to the increase in conceptual understanding, GeoGebra's availability as a free resource has significant consequences for promoting equity in mathematics instruction. It corresponds with the concepts of educational inclusivity, erasing barriers that often restrict students' access to advanced learning resources. For its easy and free installation unlike other commercial software that have limited access, GeoGebra is highly preferred by both teachers and students (Tamam & Dasari, 2021).

The accessibility of GeoGebra is particularly essential when considering international assessments such as the Programme for International Student Assessment (PISA), which evaluates the effectiveness of educational systems of countries all over the world. According to the PISA (2022) results, students who were exposed to ICT-based learning environments demonstrated higher mathematics reasoning abilities (OECD, 2023). Additionally, a systematic literature review conducted by Odell et al. (2020) showed that there is a positive relationship between students' interactions with ICT and their PISA mathematics scores. Although there is a strong correlation between the economic development of countries and the math scores of their students (OECD, 2023), ICT tools have a crucial role in promoting educational equity through reducing financial obstacles and providing fair learning opportunities.

High School 3D Geometry Lessons in Türkiye

Three-dimensional (3D) Geometry, most commonly in the Euclidean space, is a subfield of mathematics that considers spaces and objects in three dimensions. Euclid, who is known as the father of Geometry, defined a three-dimensional object as a solid that has length, breadth, and thickness (Ostermann & Wanner, 2012). The physical world in which we live is also three-dimensional since from any point there can pass three mutually perpendicular straight lines, meaning that each one is perpendicular to the other two in the Cartesian coordinate system (Adams & Essex, 2018). With regard to such a Cartesian coordinate system, the three-dimensional coordinates of a point P represent an ordered triple of real numbers, (x, y, z).

In the book *A Complete Course: Calculus*, Adams and Essex (2018) mentioned that there are three coordinate planes (xy-plane, xz-plane, and yz-plane) that split 3-space into eight octants, such as the x- and y-axes divide the xy-plane into four quadrants. In addition to Euclidean Geometry (coordinate systems, lines, planes, spheres, balls, etc.), the writers also described 3D Geometry in linear algebra (dot product, cross product, inner product space, etc.) and calculus (gradient, curl, Stokes' theorem, divergence theorem, etc.). However, the focus of this section will be three-dimensional Euclidean Geometry.

Around 300 B.C., Euclid wrote his famous thirteen-volume book *Elements of Geometry* in which he wonderfully arranged and presented the basic ideas of Greek Geometry and number theory (Ratcliffe, 2006). Euclid developed the axiomatic method that is currently used to dominate all of what is now known as 'pure mathematics' through his explicit and methodical use. He presented mathematical concepts in a meticulous and systematic way by building his geometric reasoning on a set of definitions, postulates (axioms), and commonly accepted assumptions (Byer et al., 2010).

The Elements has been published in a number of editions and translated into many languages over the decades. Each translation may provide its own analysis, notes, or interpretations of Euclid's original work. The book *The Elements of Euclid*, translated and edited by Simson (1838), presents the fundamental principles of geometry through a series of propositions, proofs, and logical deductions. The 11th book of *Elements*, Spatial Geometry and Solids, is also translated by Simson (1838). He defined the properties of prisms, pyramids, cylinders, cones, and spheres:

> A pyramid is a solid figure contained by planes that are constituted between one plane and one point above it in which they meet. A prism is a solid figure contained by plane figures, of which two that are opposite are equal, similar, and parallel to one another; and the other parallelograms. A sphere is a solid figure described by the revolution of a semicircle about its diameter, which remains unmoved. A cone is a solid figure described by the revolution of a right-angled triangle about one of the sides containing the right angle, whose side remains fixed. A cylinder is a solid figure described by the revolution of a right-angled parallelogram about one of its sides which remains fixed. (Simson, 1838, pp. 156-157)

Euclid's work in this book established the foundation for comprehending and researching three-dimensional geometry, and its enduring impact is notably observed in the crucial part Euclidean Geometry plays in the teaching of mathematics in high school.

According to the Mathematics Standards for high school students published by NCTM (2000), Geometry provides a way to describe, examine, comprehend, and find beauty in the structures of the world. In order to gain a deeper understanding of significant geometric concepts, high school students need to undertake increasingly independent investigations. With these understandings, students will be able to respond to inquiries that have always been at the heart of Euclidean geometry instruction: What is the reason for the congruence of two geometric figures? What about other attributes that can be deduced from the properties of a geometric object? (NCTM, 2000). NCTM standards for high school students in 3D Geometry are given below:

> Use visualization, spatial reasoning, and geometric modeling to solve problems; draw and construct representations of two- and three-dimensional geometric objects using a variety of tool; visualize three-dimensional objects from different perspectives and analyze their cross sections; use vertex-edge graphs to model and solve problems; use geometric models to gain insights into, and answer questions in, other areas of mathematics; use geometric ideas to solve problems in, and gain insights into, other disciplines and other areas of interest such as art and architecture.
>
> (NCTM, 2000, p. 308)

Similarly, MoNE in Türkiye has comprehensive standards addressing the geometric concepts. These standards reflect the continued significance of Euclidean geometry in mathematics education as well as the global recognition of geometric ideas as cornerstones of mathematical reasoning (Argün et al., 2010). In the mathematics curriculum outlined by Turkish MoNE in 2018, 3D Geometry is included in both 10th and 11th grades as a basic component of geometric knowledge and mathematical ability. The objectives are given in Table 1 (MoNE, 2018, pp. 31 & 34):

Table 1

10th and 11th grade three-dimensional Geometry objectives

Learning subject	10.6.1. Solids	11.6.1. Solids
Terms and concepts	right prisms, right pyramids, height, base area,	right circular cylinder, right circular cone, sphere,

Learning subject	10.6.1. Solids	11.6.1. Solids
	surface area, lateral area, volume	main axis, apex point
Learning outcomes	10.6.1.1. Students should be able to form the relationships of length, area, and volume of right prisms and right pyramids. o It is bounded by triangular, quadrilateral, and hexagonal right prisms/pyramids. o Real-life problems are included. Information and communication technologies are utilized.	11.6.1.1. Students should be able to perform operations by forming relationships between area and volume of sphere, right circular cylinder, and right circular cone. o Real-life problems are included. Information and communication technologies are utilized.

The objectives outlined in the high school curriculum show a diverse approach to teaching and learning mathematics. The aim is to provide students with the necessary tools for comprehending and working with three-dimensional objects by incorporating concepts like spatial thinking, visualization, and problem-solving. Also, students are encouraged to acquire a comprehensive understanding of geometric relationships through a combination of theoretical inquiry and the technology used. Through the use of technology as an instructional tool, the curriculum seeks to develop a generation of mathematically literate people who can apply geometric concepts in practical settings.

Teacher Training and Implementation

In the quickly changing field of education, integrating ICT tools effectively has great potential to change traditional pedagogical techniques, especially when it comes to teaching 3D Geometry. Effective use of technology would support both instructors and students in their exploration of mathematical concepts and have a significant impact on the content and learning process of mathematics among students (McCulloch et al., 2018). In 2016, Drijvers et al. mentioned that the teacher's capacity to incorporate digital resources is an essential component when teaching mathematics in a classroom. However, a study conducted in Malaysia revealed that just 15.3% of instructors use GeoGebra in their math classes, although the Mathematics Curriculum advocates using GeoGebra, and teachers believe their students struggle with geometry (Musa et al., 2021).

Researchers also identified a few difficulties with utilizing GeoGebra such as time limits, available facilities, and a lack of exposure to the program. It is advised that curriculum designers and training courses offer educators with sufficient resources to enable them to properly teach Geometry by using GeoGebra (Musa et al., 2021). This section will address the critical role of implementation techniques of ICT tools and teacher training programs in improving the teaching and learning experience in Turkish High School Mathematics classes.

Teacher training programs are the cornerstone of initiatives to provide educators with the knowledge and abilities needed to successfully use ICT teaching and learning technologies. Das (2019) recommended updating curriculum and educational policies on a regular basis to reflect changing demands, conducting professional development courses to improve teachers' attitudes towards the use of ICT regularly, and regulating teacher training programs based on the usage of ICT teaching and learning tools. Similarly, Wastiau et al. (2013) mentioned that it is crucial that teachers acquire the knowledge and abilities to integrate ICT tools into their regular teaching practices to maximize their potential to aid in enhancing students' digital competency. Essentially, many researchers highlighted that ICT tools should be introduced to mathematics teachers so that students may investigate mathematics from a broader perspective and develop their critical and creative thinking skills (Arbain & Shukor, 2015; Bhagat & Chang, 2015; Higgins et al., 2012).

In Türkiye, a number of initiatives and programs have been implemented to improve the ability of educators to use technological tools in their teaching methods. MoNE has organized seminars and workshops for professional development that are specifically designed to meet the needs of mathematics teachers, especially for 3D Geometry (MoNE, 2022). These training programs include a wide range of subjects, such as the selection and application of ICT resources, curriculum alignment, and pedagogical approaches to use ICT tools in the classroom. The main aim of these programs is to provide teachers with necessary skills to examine and use DGS effectively to develop e-materials for mathematics lessons (ÖBA, 2022).

Although there are several initiatives and programs for teachers to improve their understanding in using ICT teaching and learning tools in mathematics classes, a number of obstacles and difficulties persist in the effective integration of ICT tools in mathematics instruction. One of the challenges is the digital gap, which shows itself as differences in teachers' and students' access to technology and internet connection. In 2018, Alruwais et al. mentioned that the inadequate technological infrastructure is one of the most significant difficulties of ICT integration in classrooms. Moreover, Almanthari et al. (2020) concluded that the majority of the teachers agreed that their students did not have enough access to technological devices and internet connection for e-learning purposes.

Even though the lack of digital access is a big limitation, the most crucial task may be overcoming the barriers that keep educators from integrating technology into the classroom such as lack of training and support, traditional teaching practices, and limited relevance. According to Fu (2013), the majority of barriers in using ICT tools in classrooms are related to the instructors' lack of training and support. As Hutchison and Reinking (2011) report, the main goal is not only to teach educators new technologies on a technical and practical level; educators should be persuaded of the pedagogical advantages of ICT and how to integrate it with traditional teaching principles. In 2017, Aslan and Zhu claimed that pre-service teachers should enhance their ICT skills and re-design ICT-related courses to better utilize it in teaching, considering pedagogical knowledge, subject content, and the programs.

In the Turkish educational landscape, integration of ICT teaching and learning technologies continues to be a big challenge because of teachers' inadequate training and understanding of these tools. A study conducted by Birgin et al. (2020), showed that Turkish mathematics teachers do not have sufficient knowledge and experience of using ICT tools in mathematics classes although most of them have their own computer, smart phone, and Internet access. Doğan (2012) suggested that the Turkish teacher education programs should focus on enhancing ICT knowledge through activities that support teachers' views, performance, and confidence in using technological tools for professional teaching, both in their future careers and during their education. Additionally, Gulbahar (2008) pointed out that it is crucial for instructors in education faculties to work with technology experts to integrate the technology into the curriculum and matriculate technology-competent teachers. Also, she mentioned that teachers need to create lesson plans that are rich in technology to improve both the quality and quantity of courses.

Eventually, several key issues emerged from the analysis of teacher preparation programs and implementation techniques in mathematics classrooms in high schools in Türkiye. It becomes very clear how important it is to design extensive training programs that are unique to the demands of mathematics teachers and how essential it is to have continuous support systems in place to encourage the effective implementation of ICT teaching and learning tools. Effective implementation models of ICT tools highlight the value of monitoring educational changes, focused professional development programs and collaborative learning experiences (Forkosh-Baruch & Avidov-Ungar, 2019), even in the face of obstacles like the digital divide and resistance to change (Özcan-Alp & Baycan, 2024).

In order to overcome these obstacles, educators may work together to improve their ICT skills, provide an environment that encourages experimentation and creativity, and offer sufficient infrastructure and resources. The quality of teacher preparation programs and the efficacy of implementation techniques play a vital role in the successful integration of ICT technologies in high school lessons (Tondeur et al., 2012). To conclude, education faculties should develop comprehensive ICT training programs for pre-service teachers that encourage them to use technology to improve student engagement, develop conceptual understanding, and build 21st century skills by addressing the inherent obstacles and utilizing creative solutions.

Instructional Technology Courses in Secondary Mathematics Education Faculties in Türkiye

Over the last 20 years, there has been a growing interest in the use of instructional technologies in mathematics education, both internationally and in the Turkish educational context. Instructional technologies play a significant role in teacher training programs by providing knowledge and skills that pre-service teachers need to successfully implement technology into their lesson plans and classroom activities (Yetik et al., 2019). Accordingly, mathematics education faculties have begun to recognize that instructional technology courses are crucial for training prospective teachers to use technology in their classrooms, encourage 21st century skills, and provide equitable access to education.

In 2018, several changes were made in teacher training undergraduate programs with the partnership of MoNE and YÖK. As a result of these changes, the course Instructional Technology and Material Development is included in all education programs, with two hours of theory. The content of this course is given as follows:

> Information technologies in education; classification of teaching process and teaching technologies; theoretical approaches to instructional technologies; new trends in learning approaches; current literacies; instructional technologies as tools and materials; design of teaching materials; designing thematic teaching materials; creating a field-specific object warehouse, teaching material evaluation criteria. (YÖK, 2018, p. 6)

The aim of this section is to investigate the current status of Instructional Technology and Material Development courses offered in secondary mathematics education faculties in Türkiye, with a particular emphasis on curriculum design, pedagogical techniques, and the integration of ICT tools into teacher training programs. By scrutinizing the content, objectives, and outcomes of these courses, this review of literature on teacher training programs seeks to provide insight into the initiatives being undertaken to improve pre-service teachers' proficiency in using technology to promote mathematics teaching and learning.

The majority of secondary mathematics education faculties in Türkiye offer Instructional Technology and Material Development courses in their curricula for teacher education programs. After completing these courses, pre-service mathematics teachers are expected to have the knowledge and skills needed to integrate a variety of technological tools and resources into their mathematics lessons. However, there may be differences across faculties in the scope of curricular integration and the areas of emphasis for Instructional Technology and Material Development courses. For example, there is no required course named Instructional Technologies and Material Development in Hacettepe University, instead students are free to add MTE158, Material Development, as an elective course (Hacettepe University, n.d.). However, the majority of the universities have at least one required course, in which pre-service teachers learn about the integration of ICT tools into the mathematics lesson.

According to the official websites of the universities (Boğaziçi University, n.d.; Gazi University, n.d.; Hacettepe University, n.d.; METU, n.d.), the content of Instructional Technology and Material Development courses covers a range of topics, including the concepts and principles of educational technology as an integrated part of the teaching and learning process; basic information technology skills; selection, development, implementation, and evaluation of media with regard to learning theories; the characteristics of instructional technologies; their role in the instructional process; and the development of teaching materials.

The main learning goals of these courses are to help students understand the changes observed in the field of education and the role of instructional technologies in the learning process; and use the procedures for selecting, modifying, and designing instructional materials. The integration of Instructional Technology and Material Development courses in secondary mathematics education in Türkiye is crucial for future teachers, but continuous improvement is needed to address challenges and adapt to the 21st century digital world.

Theoretical Framework: TPACK

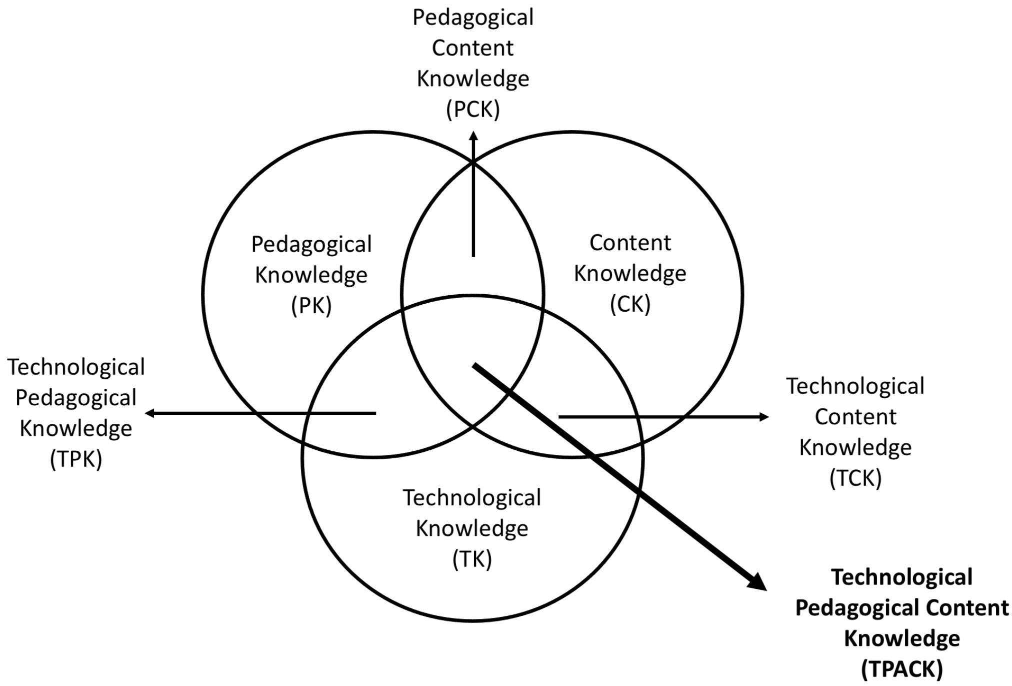
The integration of ICT in education, especially when teaching 3D Geometry, necessitates a comprehensive understanding of the interactions between technology, pedagogy, and content. The Technological Pedagogical Content Knowledge (TPACK) framework, created by Mishra and Koehler (2006), provides a solid theoretical model for comprehending this integration. By adding technology as a crucial component, the TPACK framework extends Shulman's (1986) concept of Pedagogical Content Knowledge (PCK) and provides educators with a more nuanced understanding of how to effectively integrate content knowledge, pedagogical knowledge, and technological knowledge to improve learning outcomes.

The TPACK framework comprises seven distinct components as shown in Figure 1 (Mishra & Koehler, 2006): 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).

Figure 1

TPACK Framework



Note. Adapted from *TPACK: A framework for integrating technology in teachers' knowledge*, by P. Mishra and M. J. Koehler, 2006.

Components of TPACK

Content Knowledge (CK) describes a teacher's comprehension of the subject matter, which includes the ideas, theories, and facts relevant to a particular field. In the context of 3D Geometry, CK entails understanding of geometric concepts, properties of shapes, and spatial reasoning (Mishra & Koehler, 2006).

Pedagogical Knowledge (PK) includes the teacher's comprehension of instructional techniques, approaches, and methods that promote learning. PK involves understanding how to manage a classroom, design curriculum, assess students' comprehension, and adapt teaching methods to diverse learners (Mishra & Koehler, 2006). Technological Knowledge (TK) involves the teacher's proficiency with a range of technologies and their comprehension of how to use technological tools to improve student learning. This includes knowledge of hardware, software, and digital resources that can be utilized in the classroom (Mishra & Koehler, 2006).

Pedagogical Content Knowledge (PCK) represents the intersection of pedagogy and content knowledge, which involves understanding how to teach specific content in a way that helps students to grasp it (Mishra & Koehler, 2006). In 3D Geometry, this might involve understanding which instructional techniques to use to assist students understand complex spatial concepts. Technological Content Knowledge (TCK) is the comprehension of how particular subject matter knowledge may be represented and communicated through technology (Mishra & Koehler, 2006). For example, using DGS like GeoGebra to visualize and explore geometric shapes.

Technological Pedagogical Knowledge (TPK) involves comprehending how various technologies can facilitate different pedagogical approaches. To promote learning, it is essential to understand how to select and use technological tools that are in line with teaching methods (Mishra & Koehler, 2006). Finally, Technological Pedagogical Content Knowledge (TPACK) is at the heart of the framework, which represents the integrated knowledge that teachers need to effectively teach content using technology while employing sound pedagogical practices. It encompasses the ability to effectively combine technology, pedagogy, and content in a way that improves instruction (Mishra & Koehler, 2006).

Relevance of TPACK

The TPACK framework is relevant to this study since it offers a methodical technique for examining how pre-service mathematics teachers and their instructors perceive and integrate ICT in their teaching practices. This study aimed to determine how effectively ICT tools are being used to teach complicated geometric ideas by examining the interaction between technological, pedagogical, and content knowledge. Moreover, TPACK provides a framework for evaluating how well Instructional Technology and Material Development courses prepare pre-service teachers to use ICT in the classroom. By concentrating on the integration of these three knowledge domains, the study can highlight opportunities for development and identify gaps in the present teacher education programs.

In the context of teaching 3D Geometry, the TPACK framework helps in the identification of certain technology-integrated teaching strategies that improve students' spatial understanding and problem-solving abilities when teaching 3D Geometry (Adulyasas, 2021). For example, teachers may design interactive, manipulable geometric constructs with DGS like GeoGebra that allow students to visualize and explore geometric properties in a more engaging and interesting way. This encourages critical thinking and active learning as well as helping in conveying complex geometric concepts (Dışbudak, 2017).

In conclusion, the TPACK framework provides a comprehensive lens through which to examine the integration of ICT tools in 3D Geometry lessons. This study intends to offer important insights into how pre-service mathematics teachers and their instructors might use technology to improve the teaching and learning of 3D geometry by investigating the intersections of content, pedagogy, and technology. The findings of this study are expected to contribute to the development of more effective instructional technology courses and guidelines, ultimately supporting the goal of improving mathematics education through the thoughtful integration of ICT.

Conclusion

This chapter reviewed the literature on the usage of ICT teaching and learning tools in mathematics education. Firstly, the use of ICT tools in mathematics education was discussed and GeoGebra was introduced as an effective tool. Then, three-dimensional geometry was examined and the objectives of MoNE in Türkiye were compared with NCTM standards for high school 3D Geometry topics. Afterwards, the effectiveness of ICT tools and teacher training programs in improving teaching and learning experiences in Turkish High School Mathematics classes was explored. Then, Instructional Technology courses in Turkish mathematics education faculties, where pre-service teachers learn about GeoGebra were discussed. Lastly, the TPACK framework was presented with its components.

This study aimed to explore how pre-service mathematics teachers' perceptions with regard to effectiveness, benefits, and challenges of using ICT tools in 3D Geometry lessons vary across different universities and how sufficient the Instructional Technology and Material Development courses are at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons. As an outcome, the researcher aimed to create an ICT-integrated guideline for Prisms, based on the suggestions of mathematics education pre-service teachers and their instructors. In the next chapter, the methodology of this study is presented, which includes the approaches to examining the perspectives of pre-service mathematics teachers and their instructors.

CHAPTER 3: METHODOLOGY

Introduction

This chapter provides a detailed overview of the research design and methodology for the current study, with an emphasis on addressing the research questions and accomplishing the main purpose of the study. The chapter is organized to provide a detailed understanding of the selected research design, the sampling strategy employed, population and sample, the instrumentation utilized, data collection methods and tools, instrument validity and reliability, data collection method and analysis, teaching and learning resources, and finally, the study's internal and external validity concerns.

Research Design

The primary purpose of this mixed-methods study was to explore how pre-service mathematics teachers' perceptions with regard to effectiveness, benefits, and challenges of using ICT tools in 3D Geometry lessons vary across different universities. The secondary purpose of the study was to investigate how sufficient the Instructional Technology and Material Development courses are at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons. Lastly, the study aimed to identify how instructors at different universities perceive and integrate ICT tools, and what are the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools. The research questions investigated for the study were as follows:

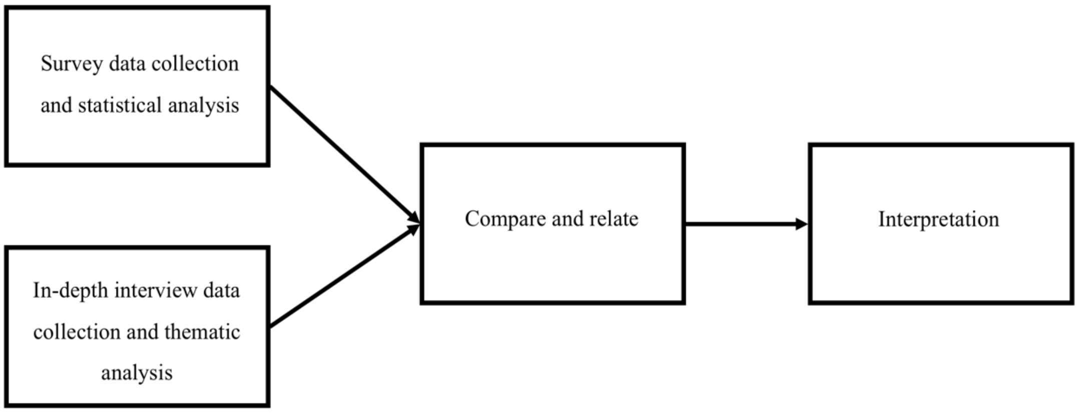
1. How do pre-service secondary school mathematics teachers' perceptions of the effectiveness and challenges of using ICT tools in 3D Geometry lessons vary across different universities?
2. How sufficient are the Instructional Technology and Material Development courses at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons?
3. How do instructors at different universities perceive and integrate ICT tools in 3D Geometry lessons, and what are the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools?

According to Creswell and Clark (2011), a convergent parallel design enables the researcher to collect both quantitative and qualitative data concurrently by providing a more comprehensive and holistic understanding of the phenomenon being studied. Since this study aimed to explore the details, relationships, and complexities between the usage of technological tools in mathematics lessons and teaching practices of pre-service teachers in education faculties, a convergent parallel design method was used to gain a comprehensive understanding of the research topic and analyze it more deeply. Qualitative thematic analysis and a quantitative Kruskal-Wallis test followed by Dunn's post hoc test for nonparametric data were combined to investigate the perceptions and experiences of pre-service teachers and their instructors regarding the integration of ICT tools in high school 3D Geometry lessons.

Convergent parallel mixed methods research design is a research design known for its capability to triangulate findings, confirm outcomes, and validate interpretations across several methodological lenses (Creswell & Clark, 2011). The main reason for choosing convergent parallel mixed methods for this study is that this method allows the validation and cross-verification of results, providing a deeper understanding of how pre-service teachers perceive the effectiveness and challenges of ICT usage and how sufficient Instructional Technology and Material Development courses are at various universities. By strengthening the validity and reliability of the study, this triangulation supports more accurate and plausible results. Since both quantitative and qualitative data are gathered concurrently in convergent parallel mixed method studies (Morse, 1991), equal priority is given for both the data and analyses independently, and the results and convergence are compared for overall interpretation, as shown in Figure 2 (Creswell & Clark, 2017).

Figure 2

Convergent parallel mixed-methods study



Note. Adapted from *Designing and conducting mixed methods research,* by J. W. Creswell and V. L. P. Clark, 2017.

In this study, the results were analyzed concurrently by triangulating the findings from both quantitative survey responses and qualitative interview transcripts.

Context

This study was conducted in four highest ranking universities in Türkiye in the field of secondary mathematics education according to the YÖK results, which translates to Higher Education Institution (YÖK, 2023). These results show the preferability rates of the universities based on the University Entrance Exam. One of these universities is located in İstanbul, whereas the other three are situated in Ankara. The population of the study consists of the instructors of Instructional Technology and Material Development courses, the courses where students learn about ICT tools, and pre-service mathematics teachers who took before or are currently taking the course Instructional Technology and Material Development in secondary mathematics education faculties.

The instructors from each university (N = 4) were interviewed to investigate how sufficient the Instructional Technology and Material Development courses are at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively and how the instructors of Instructional Technology and Material Development courses perceive and integrate ICT tools in teaching mathematics. Also, the interviews aimed to explore the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools. Online surveys were administered to the pre-service secondary school mathematics teachers (N = 79) to explore how pre-service teachers' perceptions of the effectiveness and challenges of using ICT tools in 3D Geometry lessons vary across different universities. Based on the suggestions of the instructors and pre-service mathematics teachers, an outcome of this study was to develop an example of a well-developed ICT-integrated guideline for Prisms, which is one of the subjects of high school 3D Geometry topics. The curriculum design, context, and learning outcomes of Instructional Technology and Material Development courses offered in four high ranking secondary mathematics education faculties are explained below.

University 1

Instructional Technologies and Material Development is a required course offered by the Department of Computer Education and Educational Technology in the sixth semester with the code CET 360. The content of this 3-credit course is given as follows on the website of the university:

> The concepts and principles of educational technology as an integrated part of the teaching and learning process. Basic information technology skills. Selection, development, implementation and evaluation of media with regard to learning theories. Employment of laboratories; audio-visual means, slides, graphs, films and printed materials; computer software including simulations, tutorials, drills, interactive learning environments, microworlds, intelligent systems and multimedia. (Boğaziçi University, n.d.)

The aim of the course is to help pre-service teachers explore new educational technologies and use them in mathematics lessons to provide students with effective learning through ICT tools.

University 2

In the sixth semester, the university offers Instructional Technology and Material Development course (MSE 329) for mathematics education students. Pre-service teachers attend the course 4 hours a week with 2 theoretical and 2 laboratory hours. Two main purposes of the course are to develop an understanding of the preliminary stages of instructional material development and to provide students knowledge and skills for applying the effective message design techniques while developing instructional materials (METU, n.d.). The course content is given as follows on the website of the university:

> Characteristics of various instructional technologies, the place and use of technologies in instructional process, development of teaching materials through instructional technologies (worksheets, transparencies, slides, videotapes, computer-based course materials, etc.), and assessment of the qualities of various teaching materials. (METU, n.d.)

The main purpose of the course is to help pre-service teachers engage in basic steps of instructional material development using computer applications.

University 3

There is no required course named Instructional Technologies and Material Development in University 3, instead students are free to add MTE 158, Material Development, as an elective course (Hacettepe University, n.d.). Since there is no detailed information about the content and learning outcomes of the lesson on the website, we will learn more about the course from the instructor during the interview.

University 4

University 4 offers the course Material Development (MATÖ-312) in the sixth semester as a 3 credit, required course for pre-service mathematics teachers. The main purpose of the course is to develop pre-service teachers' technological pedagogical knowledge regarding technology, visual design elements and principles, virtual manipulatives, virtual trips, exam and test preparation software, tablets, tablet software, and the use of mind board (Gazi University, n.d.).

These four universities were chosen because they are the highest-ranking in Türkiye based on YÖK results (YÖK, 2023). To improve the validity and reliability of the results, this study aimed to gather a wide range of viewpoints, experiences, and practices connected to the integration of ICT teaching and learning tools in high school mathematics lessons by incorporating universities with a strong academic reputation.

Participants

The primary purpose of this study was to explore how pre-service mathematics teachers' perceptions with regard to the effectiveness and challenges of using ICT tools in 3D Geometry lessons vary across different universities. To this end, the survey was sent to more than 100 pre-service teachers who took the course Instructional Technology and Material Development previously or are currently enrolled. However, N = 79 high school pre-service mathematics teachers voluntarily participated in the research study through online surveys. Purposive sampling was used where specifically targeted participants were selected based on their accessibility and convenience.

As shown in Table 2, 29 male and 50 female pre-service teachers participated in this study. The ages of the participants varied from 20 to 34 years old. Less than a quarter of the participants, 15.19% were under the age of 22, 74.68% were between the ages of 22 and 25, and 10.13% were more than 25 years old. The majority of the participants were seniors (n = 59), whereas only seven of them were 2nd year students, and 13 of them were in their 3rd year. Pre-service mathematics teachers in University 4 had the most impact on the results with the participation ratio of 45.57 percent. The number of participants from the other three universities were very close to each other; University 3 (n = 16), University 2 (n = 14), and University 1 (n = 13).

Table 2

Demographic Characteristics of Pre-service Teachers

Sample Characteristics	*n*	%
Gender		
Male	29	36.71
Female	50	63.29
University		
University 1	13	16.46
University 2	14	17.72
University 3	16	20.25
University 4	36	45.57
Grade		
2nd grade	7	8.86
3rd grade	13	16.46
4th grade	59	74.68
Age		
Less than 22 years	12	15.19
Between 22-25 years	59	74.68
More than 25 years	8	10.13

Secondly, the study aimed to investigate how sufficient the Instructional Technology and Material Development courses are at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively. Lastly, the aim of the study was to explore how the instructors of Instructional Technology and Material Development courses perceive and integrate ICT tools in teaching mathematics, and the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools. With this purpose, four instructors who are currently teaching the course Instructional Technology and Material Development, participated in the research study through interviews.

A purposive sampling method was used in this study to specifically target instructors of the Instructional Technology and Material Development courses who have specialized expertise and experience in integrating ICT tools into education. The names and contact details of these instructors were obtained directly from the websites of the universities, and they were sent an email for the invitation that also consisted of Bilkent Ethics Committee Approval (see Appendix C). One male and three female instructors attended the interviews. As shown in Table 3, the male instructor was a professor with more than 20 years of experience in the course Instructional Technology and Material Development, whereas the other three participants were Assistant Professors with at most 13 years of experience.

Table 3

Demographic Characteristics of Instructors

Participants	Years of Experience in this course	Academic title	Gender
Instructor 1	More than 20 years	Prof. Dr.	Male
Instructor 2	5 years	Asst. Prof. Dr.	Female
Instructor 3	13 years	Asst. Prof. Dr.	Female
Instructor 4	No experience in this course	Asst. Prof. Dr.	Female

The demographics demonstrate similarities and differences between the student participants, the four universities, and the backgrounds and professional experiences of the instructors.

Instrumentation

In this study, two methods were used to collect data: semi-structured interviews with instructors of Instructional Technology and Material Development courses in four high ranking secondary mathematics education departments in Türkiye, and an online survey given to pre-service mathematics teachers in these universities. Each instrument was meticulously created to ensure validity and reliability in gathering the necessary data.

Structured Online Survey

To explore how pre-service mathematics teachers' perceptions with regard to effectiveness and challenges of using ICT tools in 3D Geometry lessons vary across different universities, and to investigate how sufficient are the Instructional Technology and Material Development courses at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons, a structured online survey was created due its short duration and ease of process (Oppenheim, 1992). There were four demographic questions where pre-service teachers were asked about their age, gender, grade level, and the university they are currently attending. These variables were selected to capture the diversity of the respondents' backgrounds and experiences. Gender and age were chosen to investigate any differences in perceptions toward ICT tools in 3D Geometry, and grade level was included to assess how perceptions evolve through the teacher education program. The university question was essential to compare how various universities prepare pre-service teachers for using ICT tools, allowing for an analysis of institutional strengths and areas for improvement. This demographic data contributes to a comprehensive understanding of factors influencing the effectiveness of ICT in education.

After the demographic questions, the survey had 21 questions each having five possible answers, from ‘Strongly agree’ to ‘Strongly disagree’. The aim of these questions was to collect quantitative data about pre-service teachers’ perceptions in regard to effectiveness and challenges of ICT usage and explore how sufficient the Instructional Technology and Material Development courses at different universities are in preparing pre-service teachers to integrate ICT tools effectively in 3D Geometry lessons. The survey questions were developed using the TPACK framework to comprehensively assess pre-service mathematics teachers’ perceptions in regard to effectiveness and challenges of ICT usage.

TPACK guided the creation of questions that address various aspects of teaching, including technological proficiency, pedagogical strategies, and content knowledge. For example, questions aimed to explore participants’ familiarity with technology (Technological Knowledge), their ability to enhance learning through technology (Pedagogical Knowledge), and their understanding of content-specific applications (Content Knowledge). The survey’s development involved an iterative procedure involving expert feedback and pilot testing to ensure alignment with TPACK and to improve the relevance and clarity of survey’s questions.

Participants were asked about their perceptions on the effectiveness and challenges of using ICT tools in 3D Geometry lessons. Also, they were asked how competent they feel while using ICT tools and whether they are concerned about misusing the tools in their lessons. The last 10 questions were about qualification and sufficiency of the Instructional Technology and Material Development courses in secondary mathematics education faculties, and participants were asked whether there is a well-planned and up-to-date guideline on the usage of ICT tools in 3D Geometry lessons. At the end of the survey, pre-service teachers were asked about their suggestions for the content of a well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons.

The Validity and Reliability of the Survey

The survey (see Appendix A) consisted of 21 Likert-scale items with five possible answers; Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5). Firstly, the survey items have been reviewed by experts in the field, Asst. Prof. Dr. from Secondary Science and Mathematics Education Department and Asst. Prof. Dr. from Curriculum and Instruction Department. The experts were provided a copy of the survey, along with a detailed outline of the research objectives and the TPACK framework used to develop the questions. The review process involved multiple stages: firstly, the experts evaluated each question's clarity, relevance, and alignment with the TPACK domains to ensure the questions measured the intended content. They offered useful criticism on how to improve the clarity and precision of the questions, as well as suggestions for adding or changing topics to better represent the variety of pre-service teachers' perspectives. Following this input, the survey was updated and sent back to the experts for one more round of evaluation. This iterative process helped to identify and eliminate ambiguities, reduce bias, and ensure that the questions were comprehensive and aligned with the study's objectives.

To ensure the reliability of the survey instrument, an Exploratory Factor Analysis (EFA) was conducted, which is a useful method for clarifying and interpreting the data's underlying correlations and patterns (Yong & Pearce, 2013). The aim of the analysis was to confirm whether the survey items are effectively capturing the theoretical constructs they are intended to measure. Data collected from the survey responses were subjected to EFA by using SPSS (Version 29). The sample size for the analysis included responses from pre-service teachers across four universities in Türkiye. The suitability of the data for factor analysis was first assessed by using Bartlett's Test of Sphericity and a Kaiser-Meyer-Olkin Measure of Sampling Adequacy to determine whether there is a significant sphericity ($p < .05$) and to look for KMO whether it ranges between .60 and .90 (Mvududu & Sink, 2013). According to the results, there was a significant sphericity ($p < .001$) and the Kaiser-Meyer-Olkin Measure of Sampling Adequacy was equal to 0.806, which indicated that the data were appropriate for factor analysis.

Principal Component Analysis (PCA) was used for factor extraction, and Varimax rotation was applied to achieve a more interpretable factor structure. The analysis revealed five factors with eigenvalues greater than 1, explaining 69.68% of the total variance. Table 4 shows the 21 survey items (see Appendix A) grouped under each factor along with their loadings and the Cronbach's alpha for each factor.

Table 4

Factor loadings and reliability

Factor	Items	Cronbach's Alpha	Eigenvalue
1	12, 13, 14, 15, 16, 17	.86	7.79
2	18, 19, 20, 21,	.79	2.18
3	1, 2, 3, 4, 11	.75	2.08
4	5, 6, 9, 10	.74	1.52
5	7, 8	.73	1.07

The communalities for the items ranged from 0.49 to 0.86, indicating that a substantial portion of the variance in each item was accounted for by the extracted factors. The rotated component matrix showed clear loadings, with most items loading strongly on their respective factors, supporting the survey's construct validity. The high Cronbach's alpha values ($\alpha > 0.7$) for each factor indicated good internal consistency, suggesting that the items within each factor reliably measured the same underlying construct.

Factor 1, Instructional Technology and Material Development Courses, includes items related to the courses in teacher training program that pre-service teachers learn how to evaluate, describe, identify, and apply various ICT tools and materials in 3D Geometry lessons. The high Cronbach's alpha (0.86) shows excellent internal consistency.

Factor 2, A Well-planned and Up-to-date Guideline for ICT Usage in 3D Geometry Lessons, encompasses items that focus on the need for a well-planned and up-to-date guideline that includes formative assessments, self-paced activities, visual aids, and curriculum-aligned activities for ICT usage in 3D Geometry lessons. It indicates good reliability with a Cronbach's alpha of 0.79. Factor 3, Effectiveness of ICT Usage in Mathematics Teaching, covers items that assess the positive impact of using ICT tools on students' achievement, learning enhancement, and visualization of concepts in 3D Geometry lessons, along with the future use of ICT by mathematics teachers. The Cronbach's alpha of 0.75 suggests acceptable reliability.

Factor 4, Challenges of Using ICT Tools, consists of items related to the difficulties, concerns, and time consumption associated with ICT usage in 3D Geometry lessons, as well as the potential for effective future use. The Cronbach's alpha (0.74) indicates acceptable internal consistency. Factor 5, Competency and Advantages of ICT tools in 3D Geometry Lessons, includes items that highlight the competency of pre-service teachers in ICT usage and the advantages of using these tools in 3D Geometry lessons. The Cronbach's alpha of 0.73 also suggests acceptable reliability.

The results from the EFA provided strong evidence for the construct validity and reliability of the survey. The survey's efficacy as a measurement instrument was confirmed by the components that were found, which captured the targeted characteristics of pre-service teachers' perceptions on using ICT tools in 3D Geometry lessons. The last version of the survey was reviewed again by the experts in the field of education, who are mentioned above, and a small sample of respondents (n = 3).

Semi-Structured Interviews

To investigate how sufficient the Instructional Technology and Material Development courses are at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons, to identify how instructors at different universities perceive and integrate ICT tools, and to explore perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools, semi-structured interviews were created. Semi-structured interviews were chosen due to their ability to balance structure with flexibility, allowing for in-depth exploration of specific topics related to ICT usage in 3D Geometry and Instructional Technology and Material Development courses in education faculties. This approach facilitates the collection of rich, detailed responses, encourages honest and open discussion, and enables the interviewer to go deeper into topics of interest that come up throughout the interview process.

During the interviews that were held online via Zoom platform, the instructors (N = 4) were asked about their academic title and years of experience in the course Instructional Technology and Material Development. There were six open-ended questions related to the role of ICT tools in teaching 3D Geometry, advantages and disadvantages of ICT tools, Instructional Technology and Material Development courses, and pre-service teachers' engagement in the lessons. Also, the participants were asked about their suggestions of ICT-integrated guideline for Prisms. At the end of the interviews, the instructors were asked whether they want to discuss any other issues concerning implementing ICT tools.

The Validity and Reliability of the Interview Questions

The semi-structured interview protocol (see Appendix B) was created meticulously to maintain validity and reliability. Firstly, the interview questions were reviewed with experts in the field of mathematics education to ensure that the questions were appropriate, accurate, and aligned with the purposes of the study. A pilot test was also carried out with one instructor to evaluate the comprehensibility, relevancy, and clarity of interview questions. Moreover, the use of standardized procedures and clear instructions for conducting the interviews ensured the reliability of the interview protocol. All interviews were audio-recorded and transcribed to further increase reliability, data validation, and verification.

Method of Data Collection

In order to ensure relevant and accurate data collection that would enable an extensive and comprehensive review of the research questions and objectives, the data collecting techniques used in this research were carefully designed and carried out. During the data collection procedure that took approximately two months, semi-structured interviews were held with the instructors of Instructional Technology and Material Development courses, and pre-service mathematics teachers were expected to complete an online survey.

Survey Administration

An online survey was distributed to pre-service mathematics teachers from four different secondary mathematics education faculties in Türkiye to start the data collection procedure for the study. To ensure consistent and accurate completion, the survey was sent electronically via e-mail and online platforms. Clear instructions and guidelines were also included. The purpose of the study, privacy and confidentiality of their answers, and their freedom to leave the study at any moment without facing consequences were explained to the participants. Twenty-one Likert-scale items, with five possible answers ranging from ‘Strongly Agree’ to ‘Strongly Disagree’, included in the survey. The main aim of the survey was to explore pre-service mathematics teachers’ perceptions in regard to effectiveness and challenges of using ICT tools in high school 3D Geometry lessons. The survey took 5-10 minutes.

Interview Conduct

Semi-structured interviews were administered to the instructors of Instructional Technology and Material Development courses in four high ranking secondary mathematics education faculties in Türkiye. The instructors were invited via email, which included all the details about the study and Ethics Committee approval from Bilkent University (see Appendix C). After reaching out to the instructors and inviting them to take part in the research study, appointments for one-on-one interviews were made with the instructors who accepted the invitation to participate in the study.

Depending on the preferences and availability of the instructors, the interviews were conducted by video conferencing. To investigate how sufficient the Instructional Technology and Material Development courses are at different universities in preparing pre-service secondary mathematics teachers to use ICT tools effectively, to identify how instructors at different universities perceive and integrate ICT tools, and to explore the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools, a series of open-ended questions and prompts were included in the interview. With the permission of the participants, all interviews were audio recorded and transcribed to enable a comprehensive data analysis.

Data Collection Procedure

The data collection procedure took approximately two months, where participants received follow-up emails and reminders on a regular basis to encourage timely completion of the survey. The instructors shared the survey with the pre-service teachers, and adherence to the planned interview sessions. All collected data were safely kept and managed in accordance with privacy and data protection laws. To protect the participants' privacy and confidentiality, the interview transcripts were coded and deidentified.

Methods of Data Analysis

In this mixed methods study, both quantitative and qualitative data analysis procedures were followed. The interviews were analyzed with qualitative data analysis methods, whereas the questionnaires were analyzed using quantitative data analysis strategies.

Quantitative Data Analysis

Descriptive and inferential statistical methods were employed to analyze the data obtained from the online survey. Firstly, the frequencies and mean ranks of each response from the survey were computed by using SPSS (Version 29) to investigate the perspectives of pre-service teachers in regard to effectiveness and challenges of using ICT tools in high school 3D Geometry lessons. Then, the Kruskal-Wallis test

(Kruskal & Wallis, 1952) was used to explore whether there is a significant difference between the perceptions of pre-service teachers from four different universities on the usage of ICT tools. For analyzing the survey data, a Kruskal Wallis test was preferred since it is a nonparametric data analysis method ideal for comparing the perceptions of pre-service teachers from four different universities, and it can be used for ordinal data, which do not require a normal distribution. Kruskal Wallis test is suitable for examining differences across multiple independent groups, such as various universities, and it is robust against unequal group sizes. Also, it is useful for comparing differences across demographic groups like gender, age, and grade level, which makes it a complete tool for investigating variations in the effectiveness and challenges of using ICT tools in 3D Geometry lessons. Lastly, Dunn's post hoc test was conducted to compare the results of the universities in pairs for the significantly different items from the Kruskal-Wallis test.

Qualitative Data Analysis

To analyze the data gathered from semi-structured interviews, a thematic analysis method was used. According to Braun and Clarke (2006), thematic analysis is a method which describes finding, evaluating, and summarizing themes within data in six phases: familiarizing yourself with your data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report.

To become more familiarized with the data and to obtain a deeper understanding of the experiences, perspectives, and methods of the instructors of Instructional Technology and Material Development courses, the interview transcripts were read multiple times. Then, coding was conducted systematically to group the data into relevant themes and sub-themes. Finally, the data was interpreted by using the themes and sub-themes to gain a deep understanding on the sufficiency of Instructional Technology and Material Development courses at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons, how instructors at different universities perceive and integrate ICT tools, and the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools.

The present study utilized a convergent parallel mixed methods design to facilitate the integration of both quantitative and qualitative data. The data was analyzed concurrently to offer an accurate and comprehensive understanding. The findings from both quantitative and qualitative data were compared, contrasted, and synthesized. The study findings were made more credible and reliable by the triangulation of the data from both strands, which helped to confirm and verify the findings.

CHAPTER 4: RESULTS

Introduction

This study was conducted to explore how pre-service mathematics teachers' perceptions with regard to effectiveness and challenges of using ICT tools in 3D Geometry lessons vary across different universities, to investigate how sufficient the Instructional Technology and Material Development courses are at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons, and to identify how instructors at different universities perceive and integrate ICT tools and their perceptions on the benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools. Based on the suggestions of the instructors and their students, an outcome of this study was to develop an ICT-integrated guideline for Prisms that the instructors of Instructional Technology and Material Development courses can share with pre-service teachers to set an example of effective integration of technology and offer several technology-based activities. The research questions were as follows:

1. How do pre-service secondary school mathematics teachers' perceptions of the effectiveness and challenges of using ICT tools in 3D Geometry lessons vary across different universities?
2. How sufficient are the Instructional Technology and Material Development courses at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons?

3. How do instructors at different universities perceive and integrate ICT tools in 3D Geometry lessons, and what are the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools?

This chapter provides a detailed analysis, interpretation and discussion on the findings of the study that highlight the critical role of using ICT teaching and learning tools in high school 3D Geometry lessons.

Pre-service Mathematics Teachers' Perceptions on ICT Usage

One of the aims of this study was to explore how pre-service mathematics teachers' perceptions in regard to effectiveness and challenges of using ICT tools in 3D Geometry lessons vary across different universities. To this end, N = 79 high school pre-service secondary mathematics teachers who have previously taken or are now enrolled in the Instructional Technology and Material Development course voluntarily participated in the research study through online surveys. This section analyzes and discusses the survey results that were obtained from pre-service mathematics teachers.

The survey items were designed to examine participants' perceptions in regard to effectiveness and challenges of using ICT tools in 3D Geometry lessons. To compare the perceptions of pre-service teachers from four different universities, and the differences across multiple independent groups, such as gender, age, and grade level, Kruskal-Wallis test was conducted. For the significantly different items from the Kruskal-Wallis test, Dunn's post hoc test for nonparametric data was used.

Usage of ICT tools in High School 3D Geometry Lessons

Most of the pre-service teachers (n = 60, 75.95%) agreed or strongly agreed that technology-based education in mathematics teaching is more effective than a traditional instructional method, while only five of them disagreed with the claim. Also, the vast majority of the participants thought that using ICT teaching and learning tools in 3D Geometry lessons has a positive impact on mathematics achievement of high school students (n = 69, 87.34%), and it enables high school students to visualize concepts (n = 74, 93.67%) and enhance the learning process (n = 73, 92.41%).

On the other hand, almost half of the pre-service mathematics teachers (n = 32) were neutral about the challenges and difficulties of using ICT tools, while 28 of them disagreed that using ICT tools is challenging and difficult. Similarly, most of the participants (n = 56) disagreed or strongly disagreed that using ICT tools in 3D Geometry lessons is time consuming. When it comes to competency, 25 pre-service teachers agreed that they feel competent to use ICT tools in 3D Geometry lessons, whereas a considerable part of the participants (n = 56) were neutral about their confidence in ICT usage. Additionally, approximately one third of the participants (n = 26) agreed or strongly agreed that they are concerned about misusing ICT tools, one third (n = 27) were neutral, and one third (n = 26) disagreed or strongly disagreed.

In the 10^{th} and 11^{th} items (see Appendix A), pre-service mathematics teachers were asked about their opinions for using ICT tools in their future classrooms. The majority of the participants (n = 54) indicated that they will use ICT tools in 3D Geometry lessons effectively when they become in-service mathematics teachers. Also, most of them (n = 64) agreed or strongly agreed to encourage their students to use ICT tools inside and outside of their mathematics classes when they become in-service teachers.

Items 12 to 17 were about Instructional Technology and Material Development courses in teacher training programs. In general, participants were between neutral and agree choices for the items that claim Instructional Technology and Material Development courses in teacher training programs are sufficient to develop the knowledge and skills on the usage of ICT tools (n = 63, 79.75%), and they teach how to identify the concepts underlying different instructional design models (n = 68, 86.08%), how to apply visual principles when designing and producing 3D objects in Geometry lessons (n = 54, 68.35%), and how to evaluate the instructional effectiveness of various types of ICT tools for teaching and learning 3D Geometry (n = 54, 68.35%).

A couple of survey items were focused on exploring the perceptions of pre-service teachers on the need for a well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons. The majority (n = 63, 79.75%) of the participants had a positive attitude towards a guideline which includes activities that are aligned with the curriculum, formative assessments, visual aids, and self-paced activities.

Lastly, pre-service teachers were asked whether they have further suggestions for the content of the ICT-integrated guideline. One of the participants suggested to include some tools which allow students to create and manipulate geometric constructions to test conjectures, while another pre-service teacher suggested to prepare questions where students should use the ICT tools to solve the problem. Also, one of the participants mentioned that such a guideline should also be prepared for elementary school so that they become familiar with using ICT tools. Table 5 shows the frequencies of the responses for each item.

Table 5

Frequencies of the answers of pre-service teachers for each item

Items	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Technology-based education in Mathematics teaching is more effective than a traditional instructional method.	1	4	14	38	22
Using ICT teaching and learning tools in 3D Geometry lessons has a positive impact on mathematics achievement of high school students.	1	2	7	46	23
Using ICT teaching and learning tools in 3D Geometry lessons enables high school students to visualize concepts.	1	1	3	26	48
Using ICT teaching and learning tools in 3D Geometry lessons enables high school students to enhance the learning process.	1	1	4	46	27
Using ICT teaching and learning tools in 3D Geometry lessons is challenging and difficult.	4	28	32	11	4
Using ICT teaching and learning tools in 3D Geometry lessons is time consuming.	24	32	17	5	1
The advantages of using ICT teaching and learning tools in 3D Geometry lessons outweigh the disadvantages of not using it.	0	4	20	42	13
As a pre-service mathematics teacher, I am competent to use ICT tools in 3D Geometry lessons.	3	5	38	25	8
As a pre-service mathematics teacher, I am concerned about misusing ICT tools in 3D Geometry lessons.	5	21	27	18	8
When I become an in-service mathematics teacher, I will use ICT tools in 3D Geometry lessons effectively.	1	4	20	41	13

Items	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
When I become an in-service mathematics teacher, I will encourage my students to use ICT tools inside and outside of their mathematics classes.	1	4	10	47	17
Instructional Technology and Material Development courses in teacher training programs are sufficient to develop my knowledge and skills on the usage of ICT tools in 3D Geometry lessons.	4	12	25	27	11
Instructional Technology and Material Development courses in my teacher training program taught me how to identify and describe the major steps and concepts underlying different instructional design models.	1	10	17	37	14
Instructional Technology and Material Development courses in my teacher training program taught me how to describe the characteristics, advantages, limitations, and instructional applications of ICT tools in 3D Geometry lessons.	0	6	19	45	9
Instructional Technology and Material Development courses in my teacher training program taught me how to apply visual principles when designing and producing 3D objects in Geometry lessons.	0	5	20	37	17
Instructional Technology and Material Development courses in my teacher training program taught me how to evaluate the instructional effectiveness of various types of ICT tools for teaching and learning 3D Geometry.	0	9	16	40	14
Instructional Technology and Material Development courses in my teacher training program provide well-planned and up-	1	5	21	32	20

Items	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
to-date guidelines for using ICT tools in 3D Geometry lessons.					
A well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include activities that are aligned with the curriculum.	1	0	6	40	32
A well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include formative assessments.	1	3	12	36	27
A well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include visual aids.	1	1	8	39	30
A well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include self-paced activities.	1	2	8	41	27

Perceptions of Pre-service Teachers from Different Universities

Firstly, Kruskal-Wallis test for nonparametric data (Kruskal & Wallis, 1952) was used to explore how pre-service teachers' perceptions in regard to effectiveness and challenges of using ICT tools in 3D Geometry vary across different universities. Then, Dunn's post hoc test was conducted to compare the results of the universities in pairs for the significantly different items from the Kruskal-Wallis test. The aim of this analysis was to determine statistically significant differences between pre-service teachers' perceptions who are attending different universities and focus on pairwise comparisons of the universities. Table 6 shows the statistical significance between the mean ranks of four different groups, pre-service teachers from different universities.

Table 6

The Kruskal-Wallis test statistics between four groups

Items	Kruskal-Wallis H	*df*	*p*
Technology-based education in Mathematics teaching is more effective than a traditional instructional method.	4.02	3	.26
Using ICT teaching and learning tools in 3D Geometry lessons has a positive impact on mathematics achievement of high school students.	5.48	3	.14
Using ICT teaching and learning tools in 3D Geometry lessons enables high school students to visualize concepts.	3.45	3	.33
Using ICT teaching and learning tools in 3D Geometry lessons enables high school students to enhance the learning process.	1.16	3	.76
Using ICT teaching and learning tools in 3D Geometry lessons is challenging and difficult.	2.17	3	.54
Using ICT teaching and learning tools in 3D Geometry lessons is time consuming.	1.36	3	.72
The advantages of using ICT teaching and learning tools in 3D Geometry lessons outweigh the disadvantages of not using it.	3.47	3	.32
As a pre-service mathematics teacher, I am competent to use ICT tools in 3D Geometry lessons.	13.38	3	<.001*
As a pre-service mathematics teacher, I am concerned about misusing ICT tools in 3D Geometry lessons.	0.77	3	.86
When I become an in-service mathematics teacher, I will use ICT tools in 3D Geometry lessons effectively.	3.53	3	.32
When I become an in-service mathematics teacher, I will encourage my students to use ICT tools inside and outside of their mathematics classes.	1.61	3	.66
Instructional Technology and Material Development courses in teacher training programs are sufficient to develop my knowledge and skills on the usage of ICT tools in 3D Geometry lessons.	12.21	3	.01*
Instructional Technology and Material Development courses in my teacher training program taught me how to identify and	6.11	3	.11

Items	Kruskal-Wallis H	*df*	*p*
describe the major steps and concepts underlying different instructional design models.			
Instructional Technology and Material Development courses in my teacher training program taught me how to describe the characteristics, advantages, limitations, and instructional applications of ICT tools in 3D Geometry lessons.	2.85	3	.42
Instructional Technology and Material Development courses in my teacher training program taught me how to apply visual principles when designing and producing 3D objects in Geometry lessons.	0.20	3	1.00
Instructional Technology and Material Development courses in my teacher training program taught me how to evaluate the instructional effectiveness of various types of ICT tools for teaching and learning 3D Geometry.	1.38	3	.71
Instructional Technology and Material Development courses in my teacher training program provide well-planned and up-to-date guidelines for using ICT tools in 3D Geometry lessons.	1.79	3	.62
A well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include activities that are aligned with the curriculum.	3.83	3	.28
A well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include formative assessments.	8.16	3	.04*
A well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include visual aids.	1.11	3	.78
A well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include self-paced activities.	4.33	3	.23

The results of Kruskal-Wallis test revealed that there was a significant difference between the answers of pre-service teachers from four different universities for how competent they feel to use ICT tools in 3D Geometry lessons, (*p*

= 0.004). Table 7 shows the differences between the mean ranks of the universities for the competence level of pre-service teachers.

Table 7

Mean Ranks of the universities for the competence level of pre-service teachers

Universities	*n*	Mean Rank
University 1	13	51.96
University 2	14	48.93
University 3	16	26.44
University 4	36	38.24

Then, Dunn's post hoc test showed that pre-service teachers from University 3 feel significantly less confident than participants from University 2 (p = 0.004) and University 1 (p = 0.001). Also, pre-service teachers from University 1 were more confident (p = 0.046) than University 4 students.

There was a significant difference between the perceptions of pre-service teachers on whether the Instructional Technology and Material Development courses in teacher training programs are sufficient to develop their knowledge and skills on the usage of ICT tools in 3D Geometry lessons (p = 0.007). Table 8 shows the differences between the mean ranks of the universities for the sufficiency of the Instructional Technology and Material Development courses in teacher training programs.

Table 8

Mean Ranks of the universities for the sufficiency of the Instructional Technology and Material Development courses

Universities	*n*	Mean Rank

Universities	n	Mean Rank
University 1	13	58.31
University 2	14	42.61
University 3	16	33.63
University 4	36	35.21

The results of Dunn's post hoc test revealed that there is a significant difference (p = 0.003) between the results of University 3 and University 1, where pre-service teachers from University 1 remarked that the Instructional Technology and Material Development courses in teacher training programs are sufficient to develop their knowledge and skills. Also, the answers of participants from University 4 were significantly different (p = 0.001) than University 1 in terms of the sufficiency of Instructional Technology and Material Development courses on developing technological knowledge and skills.

Another significant difference occurred between the pre-service mathematics teachers on the fact that a well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include formative assessments (p = 0.04). Table 9 shows the differences between the mean ranks of the universities for the inclusion of formative assessments in the ICT-integrated guideline.

Table 9

Mean Ranks of the universities for the inclusion of formative assessments in the ICT-integrated guideline

Universities	n	Mean Rank
University 1	13	44.77
University 2	14	26.46

Universities	*n*	Mean Rank
University 3	16	47.25
University 4	36	40.32

According to the results of Dunn's post hoc test, the perceptions of pre-service teachers from University 3 were significantly different (p = 0.008) than University 2 students in terms of whether a well-planned and up-to-date guideline should include formative assessments or not. Most of the participants from University 3 (n = 14, 82.35%) stated that formative assessments should be included in the guideline, while almost half of University 2 students agreed with integration of formative assessments. Lastly, the results of Kruskal-Wallis test revealed that there was no significant difference between the answers of four different groups for the remaining items in the survey (p > 0.05).

Comparison of Pre-service Teachers' Perceptions Based on their Age, Gender, and Grade Level

To compare the differences between the perceptions of pre-service teachers based on their age, gender, and grade level, Kruskal-Wallis tests were conducted. However, according to the results of the Kruskal-Wallis tests, there were no significant differences in the perceptions of pre-service teachers based on their age, gender, and grade level. This indicated that the effectiveness and challenges of using ICT tools in 3D Geometry lessons are viewed similarly across these demographic groups. Despite the diversity in these characteristics among the respondents, their perceptions on the usage of ICT tools in regard to effectiveness and challenges did not significantly vary, suggesting a consistent understanding and experience of the benefits and obstacles associated with integrating these tools in their teaching practices. This uniformity highlights that the insights gained from the study are broadly applicable across different age groups, genders, and grade levels.

Methods and Strategies Used by the Instructors

The second purpose of the study was to investigate how sufficient are the Instructional Technology and Material Development courses at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons. Also, the study aimed to identify how instructors at different universities perceive and integrate ICT tools, and what are the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools. To this end, one male and three female instructors who are currently teaching the course Instructional Technology and Material Development participated in the research study through semi-structured interviews. This section analyzes and discusses the interview results that were obtained from the instructors of Instructional Technology and Material Development courses in four high ranking secondary mathematics education departments.

Roles, Advantages, and Challenges of Using ICT Tools in Teaching 3D Geometry

In general, instructors (N = 4) mentioned that ICT teaching and learning tools have an essential role in teaching 3D Geometry in high school. They highlighted the criticality of technology usage in visualization and construction of abstract objects, which contributes to the spatial thinking abilities of students. One of the instructors explained:

> Not only in Geometry but also in Calculus, students have difficulties in visualizing 3 dimensions. Concrete materials related to this may also be insufficient. Therefore, it is necessary to support the student's spatial thinking

> ability. ICT tools are also very helpful in this regard. They make it easier to visualize and turn things over in students' minds. Although concrete materials, such as cylinders, are also useful, I think GeoGebra is more effective in terms of seeing that shape by structuring it step by step. Since there is a construction process in GeoGebra in the activities of creating the surface area or volume of the cylinder, the student can think of building a solid object in similar situations (I1).

Similarly, another instruction stated that *"It enables students to visualize the images and manipulate them. Of course, it is better to use ICT tools in Geometry instruction so that students can visualize geometric shapes or formulas better. They would have a chance to manipulate the geometrical objects in a virtual, computer-based, environment."* (I4). Not only for visualization, but also for examination, generalization, and seeing patterns, instructors mentioned that ICT has a crucial and active role *"I think ICT tools have a very active role and teachers should use it very easily, just like a 'toy', in accordance with the mathematical achievement they want. Especially conceptual understanding, visualization, examination, generalization, discovery, concretization, seeing patterns..."* (I2).

During the interviews, many instructors mentioned that the advantages of using ICT tools outweigh the disadvantages of not using it. One of the participants stated that *"I don't think it has any disadvantages, nor do I see it as a waste of time."* and gave an example *"Let's assume that a makeshift rocket is built to send a vehicle to the Moon, it may explode on the way without enough preparation. But it is more important to send it after months or years of preparation, and that it is not a waste of time."* (I1). This is confirmed by another participant who noted that the advantages of using ICT tools outweigh the disadvantages for both teachers and students *"Quite* *simply, I think it is very necessary for students to be able to visualize this information about solid objects or angles on the plane and to make sense of it spatially."* (I2)

In terms of the advantages of ICT tools, many instructors expressed their thoughts with several examples: *"We want students to be able to make connections, understand and relate different representations of mathematical concepts, and perform operations. We want them to be able to reason and prove. In terms of all these skills, I think tools such as GeoGebra are very useful and offer potential opportunities to the student."* (I2). However, one of the instructors warned teachers to be careful while using ICT tools like GeoGebra since our screen is 2D although GeoGebra displays 3D objects:

> It is very important that the object examined in the dynamic environment evolves and rotates from left to right. For example, 3 points I choose from different surfaces of a cube in 3D may appear linear in 2 dimensions. I think it can only be fully understood when translated. Also, a point taken on the plane may appear as if it were not on the plane. This can be prevented with virtual reality, which has become popular recently (I1).

The participant also mentioned that it is a great advantage to experience such situations that are very difficult or impossible to experience in the classroom environment, thanks to ICT tools.

On the other hand, some of the instructors also mentioned some facts that may be considered as disadvantages of ICT tools: *"Students will need a phone or tablet to use ICT tools actively. This time, they may start to become interested in other things in their devices. This may cause classroom and time management problems"* (I3). Another participant stated that students may think that they do not need to prove theorems since GeoGebra does anything for them and gave an example

"A student who sees that the sum of the interior angles of a triangle is 180 degrees through many activities in GeoGebra may be reluctant to prove it mathematically in an abstract language" (I2). However, the instructor also highlighted that this may not be a disadvantage when used effectively.

In general, although some of the participants mentioned some facts that may be considered as disadvantages of ICT tools, they agreed that the advantages are far greater, and an instructor summarized *"If the technological tool makes your learners reach the learning goals in an easier way or in a quicker way, then we may assume that this tool makes the learning process enhanced. So, if the tool enhances your teaching and your students' learning, then it is advantageous so that you can integrate into your classes"* (I4). Lastly, one of the instructors (I2) noted that *"The teacher or the school administration may face inadequacies in terms of providing technical infrastructure",* but the participant also concluded that this difficulty can be overcome with sufficient effort.

Instructional Technology and Material Development Courses

First of all, the answers of the instructors showed that each university has its own dynamic and different content in the Instructional Technology and Material Development courses. Some universities do not offer only one course named Instructional Technology and Material Development; instead, they offer two different courses such as "Instructional Technology" and "Material Development". Also, weekly hours of the courses differ from university to university. For this reason, some of the instructors are dissatisfied about the weekly hours of the course, whereas some are pleased. For example, one of the instructors mentioned that *"Instructional Technology and Material Development course in our faculty has both theoretical and laboratory sessions, but I am not sure whether the weekly hours of* *the lessons are enough or not, 2 hours of theory and 2 hours of practice per week. The lesson hours may be more."* (I1). Also, he noted that *"It may be more efficient to teach the 'Instructional Technologies and Material Design' course as 2 separate courses."* (I1). Similarly, another instruction stated that *"It is a 4 hours course in a week. We have 2 hours of class sessions, where we discuss the theoretical foundation of technology integration, and we have 2 hours of lab sessions. In those lab sessions, we usually introduce some software programs so that they can develop their own materials. I wish that the lab hours were more than now"* (I4).

On the other hand, another instructor mentioned that there are two different courses named "Technology Supported Mathematics Education" and "Computer Software in Mathematics Education" apart from Material Development courses: *"These two courses are different courses taught in two separate semesters, both 4 hours a week, both theoretical and practical courses. The courses are given to approximately 25-27 people in the laboratory. Everyone has a personal computer."* (I2). She also noted that 4 hours in both the first and the second semester is sufficient time to give the necessary gains to teacher candidates and suggested increasing the number of computer laboratories.

Likewise, another instructor stated that the course which used to be 'Instructional Technologies and Material Design', is now divided into 'Instructional Technologies' and 'Material Design' and they see GeoGebra in both courses, and she noted that *"Now, the lesson hours are enough to do practices on the usage of technological tools"* (I3). As can be concluded from the responses, the instructors of the Instructional Technology and Material Development courses have a common agreement that the weekly hours of the course should be more than 4 hours so that pre-service teachers have enough time to do practice and develop their technological skills.

Secondly, the instructors were asked about the contents of the courses and how they could be developed. One of the instructors mentioned that the content of the course in their faculty is sufficient for pre-service teachers to develop their technological skills, and explained that:

> I designed the course based on the TPACK framework. I explain this framework in the very beginning of the semester to pre-service teachers so that they bring some content and pedagogical knowledge to the class from their subject area courses. In this course, we usually harmonize pedagogical content knowledge with technological knowledge. It is an intense course where they develop several projects and materials throughout the semester (I4).

However, she mentioned that the content of the course includes only free software programs since other programs are very expensive, and she stated that *"Some other paid tools could be integrated to develop the content of the course and make it more useful."* (I4).

Similarly, one of the instructors mentioned that the course content is satisfying to teach pre-service teachers how to use ICT tools in mathematics lessons and explained that *"While the course given in the first semester is more for introductory purposes, the course given in the second semester is on ICT-integrated course design. In the second semester, we analyze, criticize, and comment on the lesson plans and mathematical activities made with these tools both in Türkiye and abroad"* (I2). Then, they mentioned that pre-service teachers are asked to design their own materials by using virtual manipulatives.

Another instructor stated that the course provides a general idea for ICT tools and explained that *"We do not expect them to gain great competence, but in general we are giving them a start. We try to show many technologies that can be used in material development within the scope of the course such as preparing presentations, using Excel, and producing videos"* (I1). For the further development of the course, the instructor mentioned that it would be better if pre-service teachers had the opportunity to apply the materials they developed in this course, and get instant feedback from their peers, teachers, and students. Also, they stated that it would be more beneficial if theory and practical courses were more integrated and gave an example *"It would be better if they used the educational philosophy, learning theory and perspective (constructivist, behaviorist…) more consciously when preparing a technology-integrated material"* (I1).

In general, some of the instructors were not happy about the weekly hours of the Instructional Technology courses and mentioned that the lab hours should be longer, so that pre-service teachers find opportunities to practice and develop their teaching skills. According to the responses, it can be seen that some faculties offer just one course named Instructional Technology and Material Development, while some of them split the course into two courses such as "Instructional Technology" and "Material Development". Based on the answers of the instructors, offering these two different courses and increasing the lab hours of the courses would be useful for each university.

Moreover, not only free software programs, but also some paid tools should be integrated into the contents of the courses so that pre-service teachers practice various types of technological tools. One of the teachers mentioned that *"We are also working on programs that help pre-service teachers to participate more actively* *in the lesson, such as Kahoot and Padlet. Also, we introduce the virtual manipulatives we use in mathematics lessons"* (I2). Then, she stated that it would be better if pre-service teachers find the opportunity to practice with more developed tools, which are not free. Lastly, instructors mentioned that it would be better if pre-service teachers had the chance to apply their own materials in a real classroom environment and get instant feedback.

How Instructors Support Pre-service Teachers to Use ICT Tools

The instructors were asked about how they support pre-service teachers to use ICT tools in their classes, how they use ICT tools in their own classes, which strategies they use, and how pre-service teachers engage in ICT-integrated activities. One of the instructors mentioned that pre-service teachers are expected to use ICT tools both in their classes and during their internship, and he noted that *"I try to use these tools frequently in my classes to support and motivate my students"* (I1). Also, the participant noted that he relates the subjects to mathematics through GeoGebra activities and asks pre-service teachers to discuss ICT integration with a constructivist perspective.

Another instructor mentioned the importance of convincing pre-service teachers to use ICT tools in their own classes by providing them with the opportunity to be excited and surprise themselves while experiencing the technological tools. She stated that she gives examples that may create more scientific conflict or surprise them and noted that *"I believe that in order to understand that these tools are effective, they should experience functions of the tools such as making sense of mathematical knowledge, visualizing and interpreting it at their own level."* (I2). Then, she gave an example related to some subjects in mathematics:

> For example, I ask a problem about finding the minimum and maximum value of a function and expect them to use GeoGebra. When they experience why the derivative is zero at the peak of a function that expresses the area of a rectangle in the form of a parabola, the routine information they have memorized for so long becomes more meaningful (I2).

Also, she mentioned that not only for high school subjects, but also for undergraduate topics, it is essential to let them experience the impact of technological tools both for high school and their own level. She stated that *"I think that it is essential for them to understand that if they can solve a geometric location problem using GeoGebra at the undergraduate level, the same thing will happen for a high school student when it comes to problems related to angles in the plane"* (I2). Lastly, she mentioned that it is very important for them to practice one-on-one; just listening and passing will not be enough; they must use the tools themselves.

The third instructor stated that she introduces ICT tools such as GeoGebra at the beginning of each semester and talks about the e-sources of the websites, different examples, and interesting activities related to each topic so that pre-service teachers learn how to use these activities in their classrooms. Also, she mentioned that *"When I include them in the activity as students, they understand how the students engage in the activities. In other words, they actually experience it as students' themselves"* (I3). Additionally, she noted that pre-service teachers realize the effectiveness of GeoGebra during their internship while they use the methods they learned in the course *"Especially, during the pandemic, almost all of them used GeoGebra in their lesson plans"* (I3). In general, the instructor mentioned that the most essential strategy to support pre-service teachers to use ICT tools in their classrooms is to give them opportunities to practice the tools themselves.

The last instructor highlighted the importance of effective integration of ICT tools. She stated that *"While integrating technology, I care about the meaningful integration in a meaningful learning environment. I do not use ICT tools just for the sake of using a technological tool. I prefer collaborative tools to encourage my students to work in groups and make the class more interactive"* (I4). Furthermore, she noted that she supports her students to use ICT tools by giving them several assignments and asking them to do some mini projects, hands-on activities, and develop materials during the class sessions. Also, she mentioned that:

> The final project of this course is creating a learning material for the selected topic and targeted level. So, pre-service teachers select a topic and a grade level, and develop materials accordingly. When they complete the course, they have ready material for their future classroom (I4).

Lastly, she noted that she uses any technological tool that would make class more interactive, authentic, and collaborative to motivate pre-service teachers to use those tools.

To conclude, the instructors mentioned that they often use ICT tools in their own lessons and expect pre-service teachers to use the tools both in their assignments and teaching practices. Also, they stated that it is essential to allow pre-service teachers to practice ICT tools on their own and get excited so that they become motivated to make their own students surprised. For this reason, they noted that it is crucial to use ICT tools not only for high school topics in education faculties, but also for undergraduate topics in mathematics departments. Lastly, they highlighted the importance of effective integration of technology where pre-service teachers actively engage in an interactive learning environment.

Instructors' Opinions about an ICT-integrated Guideline

The main aim of this study was to develop a guideline that the instructors of Instructional Technology and Material Development courses can share with pre-service teachers to explain how to integrate ICT tools (GeoGebra) in 3D Geometry lessons and offer several technology-based activities. To this end, the instructors were asked about their thoughts on technology integrated guidelines on how to use the ICT tools, GeoGebra, in high school 3D Geometry lessons effectively.

Well-planned Guideline for Using ICT Tools in 3D Geometry Lessons

In general, the instructors mentioned that there is no such guideline they share with pre-service teachers that offers technology-integrated activities. Many of them stated that they teach the course based on their own materials, experiences, and TPACK framework, but if there were such a guideline, it would be beneficial for both instructors and pre-service teachers. The instructors stated that such a guideline would be very useful for both students and teachers, especially regarding three-dimensional objects since it is one of the most difficult subjects for both high school students and pre-service teachers. Also, they noted that such a guideline would be very helpful for pre-service teachers who do not have sufficient knowledge about TPACK so that they can use ICT teaching and learning tools more purposefully and more effectively.

Instructors were asked for their opinions about the content of the well-planned and up-to-date guideline they imagine. One of the instructors mentioned that the guideline can be like an interactive textbook which includes texts, images, and dynamic elements *"For example, after giving the definition of a cylinder, there may be some activities where students can manipulate the object by using technology to discover the opened and rotated versions of it"* (I1). Also, he mentioned that it is essential to explain the purpose of the guideline clearly at the beginning and state the aim of each activity so that pre-service teachers know what they expect students to observe. Similarly, another instructor mentioned that there should be goals and objectives in the guideline, and activity steps should be given for each goal:

> *It is necessary to give hints to pre-service teachers in the form of instructions like including hierarchy between square prism, rectangular prism, and cube in an activity. Moreover, directives should be clear for both students and pre-service teachers like 'Students are expected to discover the connections between a point, a circle, and a sphere* (I2).

Also, she noted that the guideline should answer several questions: What should teachers pay attention to when choosing activities? How accurate is it as a mathematical definition? Are we sure of its mathematical accuracy? Do the activity steps encourage the student to explore, question and research? Is it an activity aimed at approval or an activity in which students will actively ask and research? How much does it relate to real life? Does it give directions regarding proof?

Another instructor mentioned that it would be useful to have detailed scenarios in such a guideline. *"For each shape, there may be activities created from different perspectives, and scenarios with possible answers of students"* (I3). The last instructor suggested integrating interactive and authentic problems, and problem-based scenarios where students can solve by using ICT tools. Also, the instructor noted that *"If I would develop such a guideline, my first focus would be on the task design. Some of the tasks may be collaborative so that students can use ICT tools in group-work while solving geometric problems."* (I4).

Next, the instructors were asked about possible challenges to develop a guideline for using ICT tools in 3D Geometry lessons. An instructor mentioned that:

> *It is necessary to take a good look at the literature to discover particular topics students have difficulties in learning or have common misconceptions in 3D Geometry. For example, students have difficulties in visualizing three-perpendicular theorem in analytic geometry. Even though we live in a three-dimensional world, we act in two-dimensions. If we flew, then we would be moving in three-dimensions. The feeling of someone driving a car and someone flying a plane is very different* (I1).

Therefore, they highlighted that it is essential to determine the objectives of the activities and what interactivity they bring to students to develop their spatial thinking skills.

One instructor mentioned the importance of the literature review *"Although it may take some time for you to develop such a guideline, I suggest you develop it based on relevant justifications from the literature so that it is useful for practice"* (I4). Moreover, she suggested that the researcher contact faculty members from universities to get feedback after completing the guideline but warned to be sure about the TPACK knowledge of the members since there are not many users of ICT tools, especially in Türkiye. Another instructor added that low dissemination may be a possible challenge of the guideline. She stated that *"Such a guideline may need a pilot study, but these types of guidelines can be applied more in school with ample resources. Even in the center of Ankara, you would expect every student to have a tablet to engage in the technology-integrated activities effectively, but they may not."* (I3).

To conclude, the instructors mentioned that there is no well-planned and up-to-date guideline they currently use in Instructional Technology and Material Development courses, but it would be beneficial to create such a guideline that helps students to integrate technological tools in 3D Geometry lessons through different activities. The instructors stressed that the aims and objectives of the guideline should be determined clearly at the beginning of each activity so that the guideline becomes more purposeful. Also, they mentioned that the directives should be given explicitly for pre-service teachers, and possible scenarios could be given for different cases in a classroom environment by creating a hypothetical student profile.

Moreover, some of the instructors stated that it is essential to include not only high school topics, but also extensions related to the field of pre-service teachers so that they can expand their content knowledge on mathematics. One of the instructors noted that *"Two frames have an important role: 1) Beyond the achievements, what should students know and to what extent? 2) What should the teacher know and to what extent?"* (I1). Lastly, the instructors strongly suggested that the researcher look at the literature deeply to discover more about misconceptions and get ideas from current instructional textbooks.

CHAPTER 5: DISCUSSION

Introduction

In this chapter, the results are synthesized, and their implications are discussed in relation to the research questions. This chapter provides an interpretation of the findings and connects them to broader theoretical and practical frameworks related to mathematics education and instructional technology. Also, it outlines this study's contributions to the literature on ICT integration in mathematics education, emphasizes the practical implications for educators and policymakers, and highlights the limitations in the execution and design of the study. Additionally, this chapter aims to propose suggestions for additional research that can expand on the results of the current study. Through this comprehensive analysis, the chapter provides a sophisticated comprehension of the methods by which ICT tools may be effectively integrated into high school 3D Geometry lessons in Türkiye, improving both teaching and learning experiences.

Overview of the Study

The primary purpose of this study was to explore how pre-service mathematics teachers' perceptions with regard to effectiveness and challenges of using ICT tools in 3D Geometry lessons vary across different universities. Secondly, the study aimed to investigate how sufficient the Instructional Technology and Material Development courses are at different universities in preparing pre-service mathematics teachers to integrate ICT tools effectively in 3D Geometry lessons. Lastly, the study aimed to identify how instructors at different universities perceive and integrate ICT tools, and what are the perceived benefits, challenges, and effective strategies for developing pre-service teachers' competency in using these tools. Based on the suggestions of the instructors and their students, an outcome of this study was to develop an ICT-integrated guideline for Prisms that the instructors of Instructional Technology and Material Development courses can share with pre-service teachers to set an example of effective integration of technology and offer several technology-based activities.

Data were collected through online surveys for pre-service teachers and semi-structured interviews for the instructors of Instructional Technology and Material Development courses from four leading universities. The main findings of this mixed method study are summarized under the following titles: perceptions on ICT usage, challenges and barriers for ICT usage, and opinions about ICT-integrated guideline.

Discussion of Major Findings

The researcher aimed to explore the opinions and perceptions of both pre-service teachers and their instructors by analyzing quantitative survey data and qualitative interview responses. The key outcomes of the study are examined focusing on pre-service teachers' perceptions in regard to effectiveness and challenges of using ICT tools in 3D Geometry lessons, whether the Instructional Technology and Material Development courses are sufficient, and instructors' perceptions on benefits, challenges, and effective strategies for developing pre-service teachers' competency in using ICT tools.

Pre-service Mathematics Teachers' Perceptions and Knowledge on ICT Usage

The results of the survey revealed that pre-service mathematics teachers have a positive attitude towards using ICT tools in high school 3D Geometry lessons. They believe that using ICT tools enables high school students to enhance the learning process, visualize three-dimensional concepts, and understand abstract concepts. Also, participants noted that the advantages of using ICT tools outweigh the disadvantages and that it has a positive impact on mathematics achievement of students. These findings align with a previous study conducted by Çavuş and Deniz (2021), where the researchers concluded that technology-based education is more effective than traditional methods of instruction in terms of enhancing the learning process and visualizing concepts. Similarly, Das (2019) mentioned that technological tools improve the learning process through the visualization of interactive educational materials.

Similar to the results of a research study conducted by Aslan and Zhu (2015), where the researchers noted that some pre-service teachers are concerned about using ICT tools because of the difficulty, time consumption, and possible misuse; the results of this study showed that some pre-service mathematics teachers are not confident about using the technological tools. Although some pre-service teachers were concerned about misusing ICT tools in mathematics lessons, they highlighted that they would use ICT tools effectively in their future classroom and encourage their students to use technological tools both inside and outside of their mathematics classes.

According to the findings of this study, pre-service teachers were neutral about whether the Instructional Technology and Material Development courses in teacher training programs were sufficient for developing technological knowledge and skills. Also, they were undecided on whether instructional technology courses teach them how to describe the characteristics, advantages, limitations, and instructional applications of ICT tools in 3D Geometry lessons. As Fu (2013) mentioned that teachers are concerned about using ICT tools because of insufficient training and support, the results of this study revealed that participants noted that instructional technology courses are not sufficient to teach pre-service teachers how to identify the concepts underlying different instructional design models, how to apply visual principles, or how to evaluate the instructional effectiveness of various types of ICT tools for teaching and learning 3D Geometry. For this reason, as Hutchison and Reinking (2011) reported, educators should be persuaded of the pedagogical advantages of ICT and how to integrate it with traditional teaching principles.

Challenges and Barriers for ICT Usage

Both instructors and pre-service teachers noted several challenges and barriers to effective ICT integration, including limited resources, inadequate training, and some educators' reluctance to adapt. The responses of the instructors revealed that inadequate training provided to pre-service teachers about ICT usage is one of the main challenges. According to the results, pre-service teachers do not feel prepared enough to incorporate technological tools in the classroom since they do not have enough opportunities to apply their technology knowledge in their practices. These findings align with the results of previous studies that concluded the traditional approaches on pre-service teachers' practices, lack of effective training, and lack of teachers' competency are the challenges related to ICT use in teaching and learning (Demiraslan & Usluel, 2008; Ghavifekr et al., 2016). For this reason, it is essential for education faculties to reorganize their curriculum with comprehensive programs focusing on ICT integration.

Pre-service mathematics teachers learn how to use and integrate ICT tools in Instructional Technology and Material Development courses. However, the responses of instructors showed that the contents, dynamics, and the weekly hours of the course differ for each university which means that there is no common curriculum and content for each mathematics education department in Türkiye. For this reason, some instructors were pleased about the course and weekly hours, whereas some were not. All in all, the responses of the instructors showed that the weekly hours of the course should be more than four hours so that pre-service teachers have enough time to practice and develop their technological skills. Also, the instructors mentioned that not only free software programs, but also some paid tools should be integrated into the content of the courses so that pre-service teachers practice various types of technological tools. These findings align with previous studies, revealing that mathematics teachers in Türkiye are facing various challenges such as a lack of technological understanding, inadequate ICT training and learning opportunities, and limited technical assistance (Gulbahar & Guven, 2008; Unal & Ozturk, 2012).

Lastly, the results showed that insufficient infrastructure for technology is another big challenge for ICT usage in schools. Some of the instructors mentioned that many schools lack the necessary hardware, including computers, reliable internet access, and advanced software to provide ICT-based instruction. Also, they stated that it is difficult for all students to equitably benefit from the developments in educational technology. These findings align with a research study conducted by Alruwais et al. (2018) which mentioned that the inadequate technological infrastructure is one of the most significant difficulties of ICT integration in classrooms. Moreover, Almanthari et al. (2020) concluded that the majority of the teachers agreed that their students did not have enough access to technological devices and internet connection for e-learning purposes. For this reason, it is essential to achieve fair access to technological resources to the effective integration of ICT in the classroom.

Opinions about an ICT-integrated Guideline

The results showed that there is no well-planned and up-to-date guideline for using ICT tools that is used by instructors and pre-service teachers in Instructional Technology and Material Development courses. However, both pre-service teachers and instructors noted that such a guideline would be quite useful, especially if it includes activities aligned with the curriculum, formative assessments, visual aids, and self-paced activities. As Akbaba-Altun (2006) mentioned in their study, supervisors, school administrators, computer coordinators, and teachers in Türkiye need well-planned and up-to-date training programs and guidelines for using ICT teaching and learning tools in classrooms.

Both instructors and pre-service teachers were asked whether they have suggestions for the content of the ICT-integrated guideline. There were different ideas such that the guideline can be like an interactive textbook which includes texts, images, and dynamic elements. Some of the pre-service teachers suggested including tools that allow students to create and manipulate geometric constructions to test conjectures, and activities where students should use the ICT tools to solve problems. Also, the answers of the instructors revealed that it may be useful to determine the aims and objectives of each activity and mention possible scenarios for different cases in a classroom environment.

According to the responses of instructors, the guideline would be useful if it explains what teachers pay attention to when choosing activities, how accurate it is as a mathematical definition, whether the activity steps encourage students to explore, question, and research, whether the tasks provide students opportunities to actively engage the activities and how much are they related to real life, and whether it gives directions regarding mathematical proofs.

Additionally, the instructors noted that it is essential to include extensions for teachers so that they expand their content knowledge in mathematics. Also, they mentioned the importance of determining the frames of what students should know and to what extent, and what teachers should know and to what extent. Lastly, the instructors suggested looking at the literature deeply to discover more about misconceptions and get ideas from current instructional textbooks. Based on the suggestions of pre-service mathematics teachers and their instructors, a well-planned and up-to-date guideline (see Appendix D) was developed for Prisms to provide an example of ICT-integrated guideline for high school mathematics lessons.

Implications for Practice

Based on the results, several implications for practice and policy can be drawn such as enhanced training programs and professional development. Also, a current policy is necessary to ensure that the use of ICT tools in mathematics education remains relevant and effective.

Enhanced Training Programs

Teacher training programs are the cornerstone of initiatives to provide pre-service teachers with the skills and knowledge they need to effectively use ICT for teaching and learning. For this reason, it is essential to establish improved teacher training programs to overcome the obstacles related to the integration of ICT tools in mathematics lessons. In 2012, Tondeur et al. highlighted that the quality of teacher preparation programs and the efficacy of implementation techniques play a vital role in the successful integration of ICT technologies in high school lessons. These programs should be comprehensive and continuous, emphasizing both the pedagogical techniques needed to effectively integrate these resources into the curriculum and the technical skills needed to use a variety of ICT tools. As Doğan (2012) suggested in their study, the Turkish teacher education programs should focus on enhancing ICT knowledge through activities that support teachers' views, performance, and confidence in using technological tools. Peer collaboration sessions, online courses, and practical workshops should be a part of teacher training so that pre-service teachers see the advantages of ICT firsthand and gain confidence in utilizing it.

Moreover, teacher training programs should include components of international curricula such as Advanced Placement (AP) and International Baccalaureate (IB) programs so that the teachers of future can better prepare their students for international educational standards and examinations. In order to improve learning outcomes and provide students the digital literacy skills they need to succeed in a technologically advanced world, technology use should be integrated into these programs. The provision of enhanced training programs, including IB and AP curricula, will equip pre-service teachers to effectively utilize ICT tools in mathematics lessons.

Eventually, it is crucial that teacher training programs provide pre-service teachers opportunities to acquire the skills necessary to incorporate ICT tools into their regular teaching practices to maximize their potential to support the development of students' digital competency. Also, including IB and AP curricula in teacher training programs that emphasize both technical and pedagogical ICT skills would improve student engagement and comprehension in mathematics lessons.

Professional Development

Professional development is crucial for providing in-service teachers with the skills and knowledge required to effectively integrate ICT teaching and learning tools in high school mathematics lessons. Professional development programs should be continuous and diverse, that offer not only technical training but also insights into innovative instructional strategies. As many researchers highlighted in their studies, ICT tools should be introduced to mathematics teachers so that students may investigate mathematics from a broader perspective and develop their critical and creative thinking skills (Arbain & Shukor, 2015; Bhagat & Chang, 2015; Higgins et al., 2012). Workshops, online courses, and seminars can provide practical experiences with ICT technologies, whereas collaborating with peers may help exchange strategies and best practices.

Furthermore, aligning professional development with international standards like AP and IB curricula ensures that teachers are prepared to meet the demands of a global learning environment. This alignment may involve instruction on how to implement technology into assessment and evaluation procedures to facilitate more dynamic and comprehensive approaches to measuring student learning outcomes. In that way, educators may successfully integrate technological tools into their lessons, thereby increasing student engagement, promoting a better comprehension of geometric ideas and improving overall educational results by investing in comprehensive professional development.

Additionally, professional development programs should include feedback systems that enable teachers to share their experiences, reflect on their techniques, and accept helpful feedback to facilitate continual progress. Mentorship programs, in which more experienced teachers advise less experienced ones, can also be quite beneficial.

To summarize, professional development programs are essential to provide teachers with the necessary tools to incorporate ICT tools into mathematics lessons. Not only with the MoNE curriculum, but also in line with the international curricula, these programs should include technical training, creative pedagogy, individualized education, and digital citizenship. Also, educators may employ technology with confidence, which enables student engagement, understanding of mathematics, and overall academic outcomes.

Collaboration and Support

Teachers, administrators, and technology experts should work together to incorporate ICT tools effectively into mathematics education in high schools. In order to improve teaching techniques and build interactive learning environments, educators should work together to share resources, best practices, and creative solutions. In this way, stakeholders can ensure that students obtain an extensive and engaging education in mathematics, especially in 3D Geometry.

Additionally, interdisciplinary collaborations are essential for enhancing the learning process and demonstrating the practical applications of geometric principles. For example, combining 3D Geometry topics with physics, computer science, and art may provide students a comprehensive understanding of how geometric principles are used in a variety of professions. This interdisciplinary and interrelated cooperation may be helpful in the creation of innovative methods and instruction that make learning more interesting for students. Also, it is crucial to establish extensive support mechanisms that enable smooth integration of technological tools. Administrative assistance is essential to ensure that educators have access to the tools they need such as money for technology, chances for professional growth, and time for collaborative planning.

Lastly, educational institutions should promote open communication and the sharing of experiences between educators and administrators to develop a sustainable culture of collaboration and support. Regular meetings and group planning sessions may be beneficial to identify obstacles and create effective strategies for ICT usage in the classroom. The integration of ICT technologies can be further supported by forming collaborations with other organizations, such as technology companies and educational institutions, which can offer extra resources and experience.

Implications for Further Research

Based on the results, several implications for further research are suggested for the implementation of ICT-integrated guideline and resource allocation. The guideline is intended for pre-service teachers, though it could certainly benefit in-service teachers, and be explored in professional development sessions.

Implementation of ICT-integrated Guideline

One of the aims of this study was to develop an ICT-integrated guideline for high school 3D Geometry lessons, but the study only focused on the Prisms. For this reason, further research may prepare guidelines for the other solids (Pyramids, Cylinder, Cone, and Sphere). Moreover, further research should focus on the practical elements of implementing the guideline into practice in various educational contexts. In other words, future studies may explore the obstacles and best practices for implementing the guideline in various school environments such as infrastructure, instructor preparedness, and student involvement. Also, it is essential to examine long-term effects of the guideline on teaching effectiveness and student learning outcomes. Additionally, modifying the guideline for wider use in other disciplines and educational levels may provide a more comprehensive approach to ICT integration.

Resource Allocation

Further research should examine efficient resource allocation techniques to support the effective implementation of the ICT-integrated guideline created in this study. It is essential to investigate how resources are currently distributed throughout mathematics education departments to identify disparities that could prevent pre-service teachers from having equal access to the guideline and ICT tools. Also, further studies should concentrate on how policymakers and educational institutions can ensure that there are enough resources available for ICT integration. Studies that evaluate the effectiveness of various financing structures and government initiatives might give essential insights into how resources can be distributed more effectively.

Limitations

Firstly, the context is one of the most significant limitations where only the best four universities were included in the study. For this reason, findings may not be generalizable to other universities from the other regions of the country. Türkiye's various socioeconomic, cultural, and institutional factors may have an impact on the efficacy of ICT tools and training programs, which may not accurately represent the experiences of educators and pre-service teachers in other nations or even within various areas of Türkiye. However, this limitation may be overcome by broadening the scope of future research to include a variety of educational settings, which will provide a more comprehensive understanding of the impacts of ICT tools in multiple contexts.

Another limitation is the reliance on self-reported data of instructors and pre-service teachers. The participants might have given responses that they think are positive instead of replies that reflect their actual opinions and experiences. Also, participants may have forgotten their old experiences on ICT usage and might not correctly have remembered the effective strategies they used before. Nevertheless, a mixed methods research design and triangulation have been used to decrease the effects of this limitation and provide more accurate evaluation of ICT integration.

This study focused on the perceptions of the participants in regard to the effectiveness and challenges of using ICT tools, rather than their actual performance or application of these tools in mathematics classes. Although it is essential to explore their perceptions, it may not give a complete picture of how effectively pre-service teachers can integrate technological tools in their lessons. Therefore, the results may not accurately reflect the real-world difficulties of classroom dynamics such as student involvement, interaction, and learning outcomes. To overcome this limitation, further research incorporating practical classroom assessments and longitudinal evaluations might be included.

Last but not least, the current changes in the Turkish educational curriculum are certainly a limitation to this study though these changes are beyond the scope of the researcher’s control until they are implemented. These changes may affect both the relevance and applicability of the recommendations of the study. The perceptions of the participants may be in line with the old curricula and may not accurately reflect the most recent educational standards and expectations because of the fast evolution of the curriculum. For this reason, the study’s findings, recommended practices, and ICT-integrated guideline may be updated to be applicable in light of continuous curriculum changes. However, an adaptable research approach is maintained by ensuring that the findings of the study are still applicable and valuable in an ever-changing educational context.

Conclusion

The results of the study and their implications were summarized by discussing the major findings about the opinions and perceptions of both pre-service teachers and their instructors on the usage of ICT tools. Several aspects of professional development, enhancing training programs, and encouraging cooperation and support among educators were explored. It became clear that ICT technologies may improve education by allowing students to gain critical 21st Century skills, creating dynamic visualizations of geometric concepts, and creating interactive and engaging learning environments.

Furthermore, this chapter highlighted the challenges and barriers for ICT usage such as limited resources, inadequate training, educators' reluctance to adapt, and lack of collaboration between the mathematics education faculties in terms of Instructional Technology and Material Development courses. For this reason, it is crucial for education faculties to regulate their curriculum with comprehensive programs focusing on ICT integration and integrate various types of technological tools into the contents of the courses. These insights also underlined the significance of having an up-to-date and well-structured guideline to help educators successfully integrate ICT technologies into their lesson plans.

To conclude, the incorporation of ICT tools into high school mathematics lessons offers essential opportunities for enhancing pedagogical approaches and improving student achievements. This study has established a complete and efficient framework for ICT integration in mathematics education by addressing the key areas of teacher preparation, professional development, collaboration, and future research. As the educational landscape continues to evolve, the insights gained from the study and ICT-integrated guideline can serve as a valuable resource for educators, policymakers, and researchers dedicated to enhancing the quality of mathematics education through effective use of ICT tools.

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Appendix A

Pre-service Teachers' Perceptions and Knowledge of ICT Usage in High School 3D Geometry Lessons

This study is being conducted by Alisa Sümeyye Uymaz as a master's thesis within the scope of the Bilkent University Curriculum and Instruction Master Program. The aim of this study is to explore pre-service mathematics teachers' perceptions in regard to effectiveness and challenges of using ICT teaching and learning tools in high school 3D Geometry lessons. The results will be used to develop a guideline that Instructional Technology and Material Development course instructors can share with pre-service teachers. The survey will take 5-10 minutes. Thank you for your time and input.

- The term 'ICT tools' (Information and Communications Technology tools) is being used to imply DGS.
- DGS (Dynamic Geometry Software) is a type of software that helps teachers and students educate and learn the relationships between geometrical behaviors and forms.
- Some examples of DGS are GeoGebra, Desmos, Sketchpad, Cabri, etc.

Please indicate your consent:

- ○ I agree to participate in this study
- ○ I do not agree to participate in this study

Please indicate the university you are currently attending:

- ○ Boğaziçi University
- ○ Gazi University
- ○ Hacettepe University
- ○ Middle East Technical University

Please indicate your grade:

- ○ 1st year
- ○ 2nd year
- ○ 3rd year

- 4th year

Please indicate your gender:

- Female
- Male
- Other
- Prefer not to indicate

Please type your birth year (i.e 2003):

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
Q1) Technology-based education in Mathematics teaching is more effective than a traditional instructional method.					
Q2) Using ICT teaching and learning tools in 3D Geometry lessons has a positive impact on mathematics achievement of high school students.					
Q3) Using ICT teaching and learning tools in 3D Geometry lessons enables high school students to visualize concepts.					
Q4) Using ICT teaching and learning tools in 3D Geometry lessons enables high school students to enhance the learning process.					
Q5) Using ICT teaching and learning tools in 3D Geometry lessons is challenging and difficult.					
Q6) Using ICT teaching and learning tools in 3D Geometry lessons is time consuming.					
Q7) The advantages of using ICT teaching and learning tools in 3D Geometry lessons outweigh the disadvantages of not using it.					
Q8) As a pre-service mathematics teacher, I am competent to use ICT tools in 3D Geometry lessons.					

Q9) As a pre-service mathematics teacher, I am concerned about misusing ICT tools in 3D Geometry lessons.					
Q10) When I become an in-service mathematics teacher, I will use ICT tools in 3D Geometry lessons effectively.					
Q11) When I become an in-service mathematics teacher, I will encourage my students to use ICT tools inside and outside of their mathematics classes.					
Q12) Instructional Technology and Material Development courses in teacher training programs are sufficient to develop my knowledge and skills on the usage of ICT tools in 3D Geometry lessons.					
Q13) Instructional Technology and Material Development courses in my teacher training program taught me how to identify and describe the major steps and concepts underlying different instructional design models.					
Q14) Instructional Technology and Material Development courses in my teacher training program taught me how to describe the characteristics, advantages, limitations, and instructional applications of ICT tools in 3D Geometry lessons.					
Q15) Instructional Technology and Material Development courses in my teacher training program taught me how to apply visual principles when designing and producing 3D objects in Geometry lessons.					
Q16) Instructional Technology and Material Development courses in my teacher training program taught me how to evaluate the instructional effectiveness of various types of					

ICT tools for teaching and learning 3D Geometry.					
Q17) Instructional Technology and Material Development courses in my teacher training program provide well-planned and up-to-date guidelines for using ICT tools in 3D Geometry lessons.					
Q18) A well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include activities that are aligned with the curriculum.					
Q19) A well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include formative assessments.					
Q20) A well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include visual aids.					
Q21) A well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons should include self-pased activities.					

Do you have further suggestions for the content of a well-planned and up-to-date guideline for using ICT tools in 3D Geometry lessons?

Thank you for your time and input.

Appendix B

Instructional Technology and Material Development Course Instructors' Perceptions on ICT Usage

1) For how many years have you been teaching an Instructional Technology and Material Development course?

2) How do you define the role of ICT tools in teaching 3D Geometry?

3) What are the advantages and disadvantages of using ICT tools in 3D Geometry lessons?

- Do you think that the advantages of using ICT teaching and learning tools in 3D Geometry lessons outweigh the disadvantages of not using it?
- Why?

4) Can you share specific examples of ICT tools that you find particularly effective for teaching 3D Geometry?

5) Do you think that this course is sufficient to develop pre-service teachers' knowledge and skills on the usage of ICT tools in 3D Geometry lessons?

- Why?
- How can it be improved?

6) How do you support pre-service teachers to use ICT tools in their own class?

- Do you use ICT tools in your classes? How? What strategies do you use? Why?
- How are pre-service teachers engaging in ICT in your course?

7) Do you think that this course provides well-planned and up to dated guideline for using ICT tools in 3D Geometry lessons?

- If yes, are there any deficiencies of these guidelines? How can they be improved?
- If no, would such a guideline be useful for the Instructional Technology and Material Development course?
- What are the possible challenges to develop such a guideline?

8) Are there any other issues concerning implementing ICT tools that you would like to discuss?

Thank you for your time, and insight into implementing ICT tools into mathematics classrooms.

Appendix C

Bilkent Ethics Committee Approval

Bilkent Üniversitesi
Akademik İşler Rektör Yardımcılığı

Tarih : 8 Mayıs 2023

Gönderilen : Sümeyye Uymaz

Danışman : Anita Nicole Alexander

Gönderen : H. Altay Güvenir
İnsan Araştırmaları Etik Kurulu Başkanı

Konu : *"The Development ..."* çalışması etik kurul onayı

Üniversitemiz İnsan Araştırmaları Etik Kurulu, 8 Mayıs 2023 tarihli görüşme sonucu, *"The Development of an ICT Guideline for High School 3D Geometry Based on Perceptions of Mathematics Education Pre-service Teachers and their Instructors"* isimli çalışmanız kapsamında yapmayı önerdiğiniz etkinlik için etik onay vermiş bulunmaktadır. Onay, ekte verilmiş olan çalışma önerisi, çalışma yürütücüleri ve bilgilendirme formu için geçerlidir.

Bu onay, yapmayı önerdiğiniz çalışmanın genel bilim etiği açısından bir değerlendirmedir. Çalışmanızda, kurulumuzun değerlendirmesi dışında kalabilen özel etik ve yasal sınırlamalara uymakla ayrıca yükümlüsünüz.

Kovid-19 salgını nedeniyle konulmuş olan kısıtlamaların yürürlükte olduğu süre içinde, tüm komite toplantıları elektronik ortamda yapılmaktadır; aşağıda isimleri bulunan Bilkent Üniversitesi Etik Kurulu Üyeleri adına bu yazıyı imzalama yetkisi kurul başkanındadır.

Etik Kurul Üyeleri:

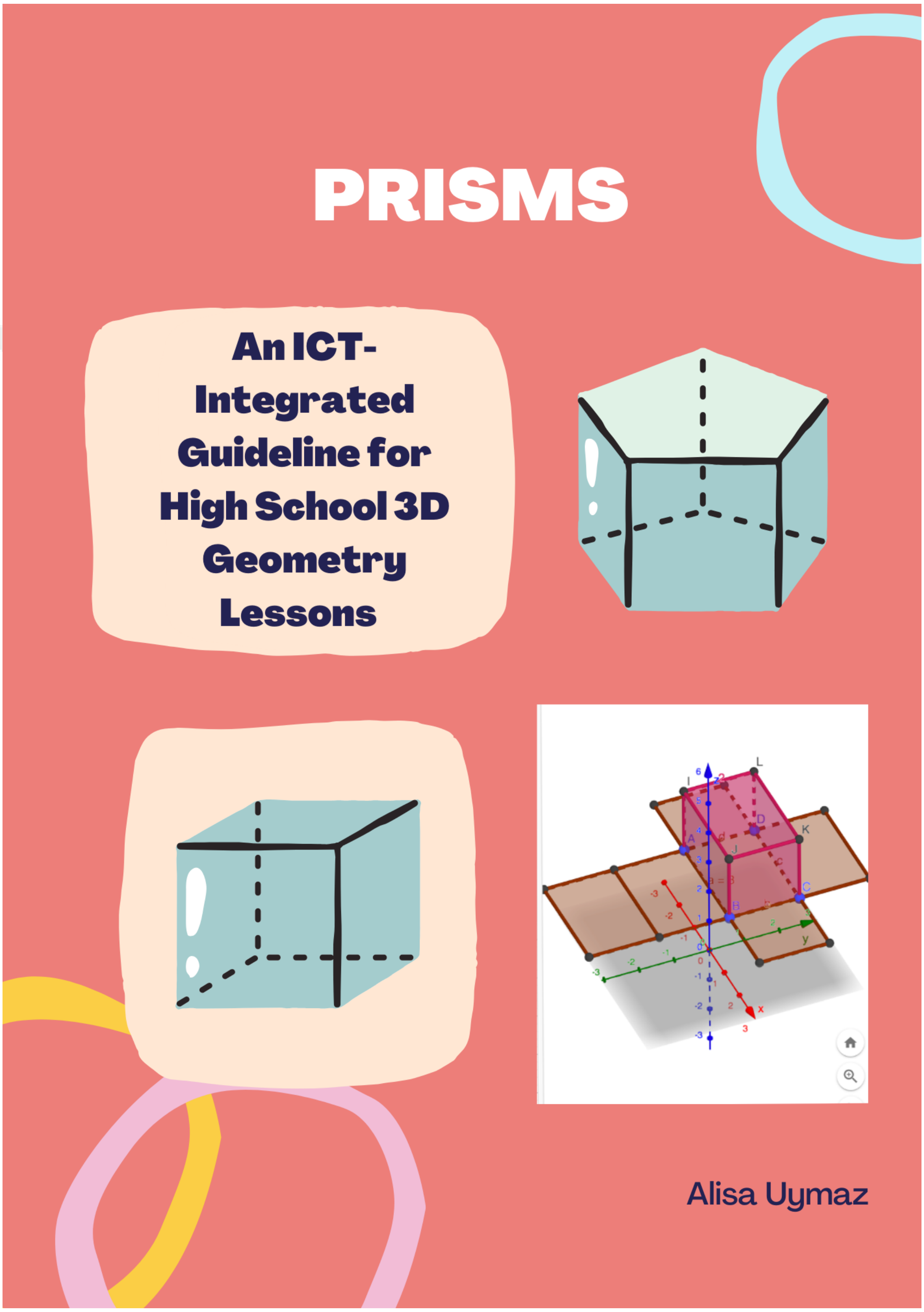
Ünvan / İsim	**Bölüm / Uzmanlık**	
Prof.Dr. H. Altay Güvenir	Bilgisayar Mühendisliği	Başkan
Prof.Dr. Erdal Onar	Hukuk	Üye
Prof.Dr. Haldun Özaktaş	Elektrik ve Elektronik Müh.	Üye
Doç.Dr. Işık Yuluğ	Moleküler Biyoloji ve Genetik	Üye
Dr. Öğr. Üyesi Burcu Ayşen Ürgen	Psikoloji	Üye
Dr. Öğr. Üyesi Didem Özkul McGeoch	İletişim ve Tasarımı	Yedek Üye
Dr. Öğr. Üyesi A.Barış Özbilen	Hukuk	Yedek Üye

Kurul karar/toplantı No: 2023_05_08_01

Bilkent Üniversitesi, 06800 Bilkent, Ankara • Telefon: (312) 290 12 13 • (312) 290 12 14 • Faks: (312) 266 41 52

Appendix D

ICT-Integrated Guideline for High School 3D Geometry Lessons on Prisms



“The purpose of using technology is
not to make the learning of mathematics easier, but richer and better.”
Alfinio Flores

This guideline is for mathematics teachers to
model and explain how to integrate GeoGebra
in 3D Geometry
lessons.

INTRODUCTION

Purpose

The purpose of this technology-integrated guideline, which is structured according to the Technological Pedagogical Content Knowledge (TPACK), is to provide mathematics teachers with a comprehensive framework for the usage of Information and Communication Technology (ICT), GeoGebra, in high school 3D Geometry lessons. The guideline intends to improve teaching and learning by introducing dynamic tools and activities that make abstract geometric topics more approachable and engaging. By creating a dynamic and student-centered learning environment, the guideline aims to empower educators with the tools and strategies to effectively use ICT tools. Additionally, the guideline promotes the growth of critical thinking, problem solving abilities, and practical applications of geometry in order to bridge the gap between traditional teaching methods and modern educational practices. Through this approach, the guideline aims to help teachers provide high-quality, technologically enhanced instruction while helping students develop a deeper understanding of 3D Geometry.

Guideline Objectives

Mathematics teachers will be able to:

1) Enhance their students' understanding of 3D Geometry by using ICT technologies

2) Encourage their students to create and manipulate geometric constructions

3) Develop their students' critical thinking and problem-solving skills

4) Encourage their students to develop connections between geometric concepts and real-world applications

MEB 2018 Standards

10.6.1.1. Students should be able to form the relationships of length, area, and volume of right prisms and right pyramids.

- It is bounded by triangular, quadrilateral, and hexagonal right prisms/pyramids.
- Real-life problems are included.
- Information and communication technologies are utilized.

NCTM 2000 Standards, Geometry

In grades 9-12 all students should be able to:

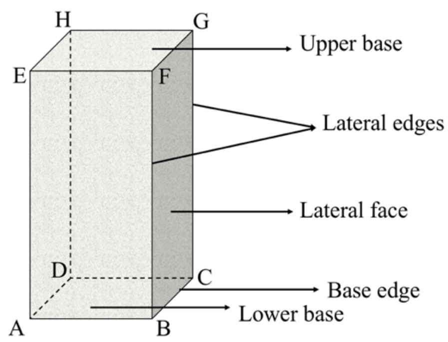
- Use visualization, spatial reasoning, and geometric modeling to solve problems
- Draw and construct representations of two- and three-dimensional geometric objects using a variety of tools
- Visualize three-dimensional objects from different perspectives and analyze their cross sections
- Use vertex-edge graphs to model and solve problems
- Use geometric models to gain insights into, and answer questions in, other areas of mathematics
- Use geometric ideas to solve problems in, and gain insights into, other disciplines and other areas of interest such as art and architecture

PRISMS

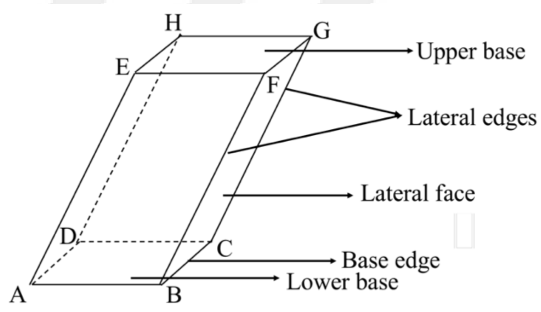
Definition

A prism is defined as a solid that has two identical and parallel bases. If the lateral edges are perpendicular to the bases, then the prism called a **right prism**. If the lateral edges are not perpendicular to the bases, then the prism called an **oblique prims**.

Right Prism



Oblique Prism



- Ask your students to discuss about the differences between a right prism and an oblique prism.

  Answer1: The lateral faces of a right prism are rectangles, while the lateral faces of an oblique prism are parallelograms.

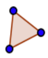
  Answer2: All the lateral edges of a righ prism meet the base at a right angle (90 degrees), while the lateral edges of an oblique prism meet the base at an angle that is not right.

- After giving the definition of a right prism, you may ask "What if the lateral edges were not perpendicular to the bases?" to your students so that they discover the properties of an oblique prism.
- Mention that the focus will be on right prism since oblique prism is not in the curriculum (MoNE, 2018).

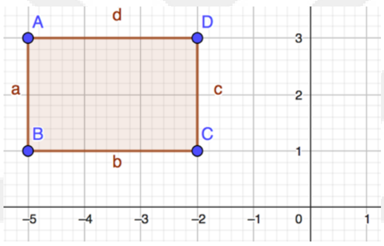
Construction of a Right Prism by using GeoGebra

- In this part, students will construct their own right prisms by using ICT tool, GeoGebra, so that their spatial reasoning and understanding of three-dimensional concepts enhances through dynamic visualization. Also, they will experience hands-on activity to link 2D and 3D Geometry which will increase their engagement, motivation, and technological skills.

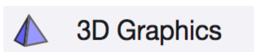
Step 1: Go to the following link https://www.geogebra.org/classic

Step 2: Clik on the following image , and choose polygon

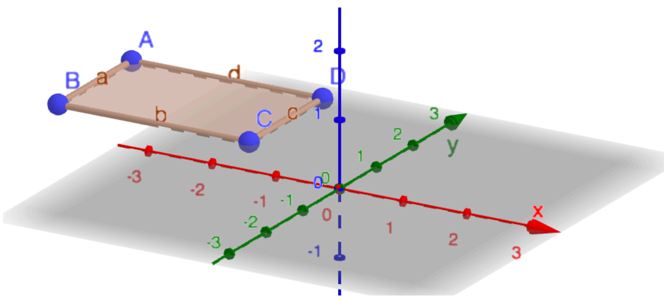
Step 3: Choose random four points in the coordinate system that are making a rectangle as shown below:



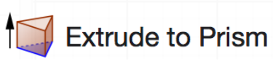
Step 4: Click on the following image , and click on

Step 5: Choose 

, and you will see the following:



Step 6: Click on the ABCD rectangle in 3D graph, and click on 

Step 7: Choose 

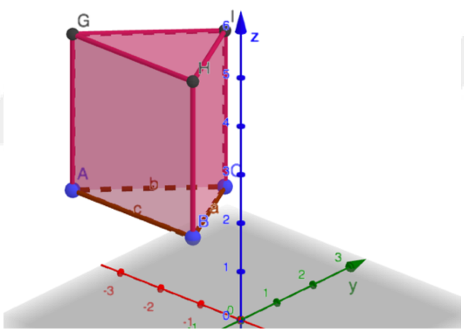
, click on the rectangle again and enter an height.

Step 8: Your prism is ready ☺ You may click on and play with your prism.

- Ask students to observe the components of the prism such as the length, widht, depth, lateral faces…
- Discuss about the properties of a right prism such that lateral faces are parallel, upper and lower bases are congruent, lateral edges are congruent, cross sections are congruent.
- That was a random prism. From now on, ask students questions like:

1) "What if we choose three points at the beginning and have a triangle as a base?"

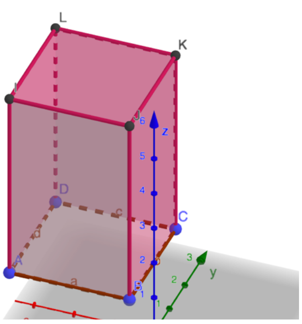
Answer: Triangular Right Prism



- Ask students to observe the triangular right prism when the triangle is a right triangle, isosceles triangle, equailateral triangle, and scalene triangle.

2) "What if we choose four points so that the base is a square?"

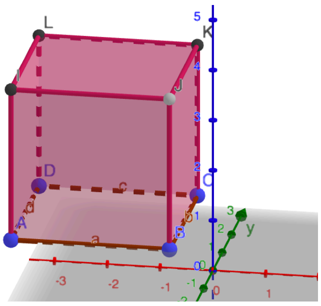
Answer: Regular quadrilateral (square) prism



- At this point, mention that a right prism with bases that are regular polygons is called a **regular prism**.

3) “What if we choose the base as a square, and the length of the height same as the sides of the square?”

Answer: Cube

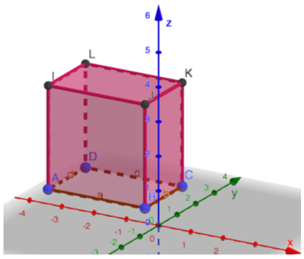


- Ask students to estimate when choosing the base as a pentagon, hexagon etc.
- Ask students to estimate when choosing the base as a regular pentagon, hexagon etc.
- Ask students what would happen if we increase the sides of the regular polygon.
- Very nice if there are students who discovered that the shape will resemble to a cylinder.

Diagonal Length of a Rectangular Prism by using GeoGebra

- In this part, students will explore the diagonal length of a rectangular prism and the length of any line drawn in the solid by using ICT tool, GeoGebra, so that their spatial reasoning and understanding of three-dimensional concepts enhances through dynamic visualization. Also, they will experience that the diagonal length changes when they change the dimensions of the prism.

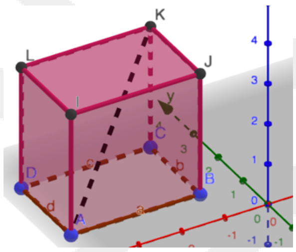
  Step 1: Go to https://www.geogebra.org/classic ,and follow the steps explained in ‘Construction of a Prism by using GeoGebra’ section. Be sure that you have a prism like shown below:



Step 2: After drawing the prism, click on , and choose segment.

Step 3: Choose two random points (preferably A and K in the first time), and draw a segment

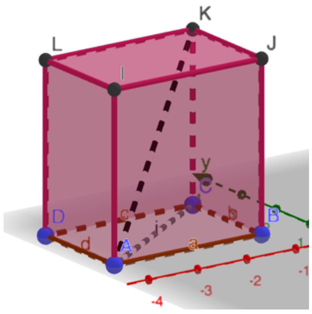
Step 4: Click on , and observe the segment as given below:



- Mention that this line segment is called 'the diagonal of solid' whose endpoints are opposite vertices of the solid.
- Ask students how many different diagonals are there in a rectangular solid, each with the same length, that cınnect each pair of opposite vertices.

  Answer: Four

- Ask students how to find the length of a diagonal
- You may draw one more line segment from A to C such as below:



- Ask students how to find the length of AC, namely i

  Answer: $\boxed{\boldsymbol{i^2 = a^2 + b^2}}$

- Draw one more line segment from C to K, namely e, and ask students to observe the right triangle ACK
- Ask student to find the length of the diagonal

  Answer: $\boxed{\sqrt{i^2 + e^2}}$, **so** $\boxed{\sqrt{a^2 + b^2 + e^2}}$
- Ask students how to find the diagonal length of a cube with edge a units

  Answer: $\boxed{a\sqrt{3}}$ **units**

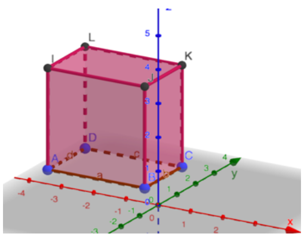
  Example: Given a rectangular prism with dimensions; 4 cm, 5 cm, and x cm. Find x where the diagonal length of the solid is 9 cm.

  Answer: $\boxed{2\sqrt{10}}$
- Do more related examples, and ask students to check their answers by using GeoGebra.

Surface Area of a Right Prism by using GeoGebra

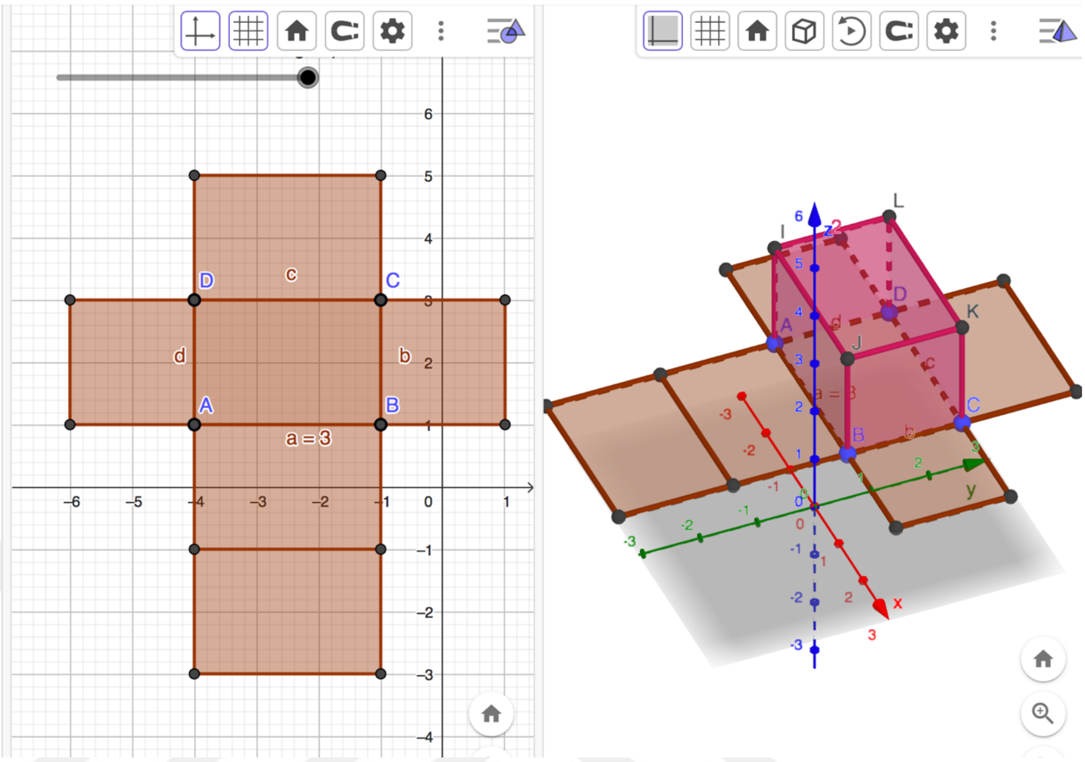
- In this part, students will explore the surface area of a right prism which is the sum of the areas of the bases and the lateral faces by using ICT tool, GeoGebra, so that they better understand the opened for of a three dimesional object through dynamic visualization.

  Step 1: Go to https://www.geogebra.org/classic ,and follow the steps explained in 'Construction of a Prism by using GeoGebra' section. Be sure that you have a prism like shown below:



Step 2: Click on , and choose 

Step 3: After clicking on the solid, you will see the opened form as shown below:

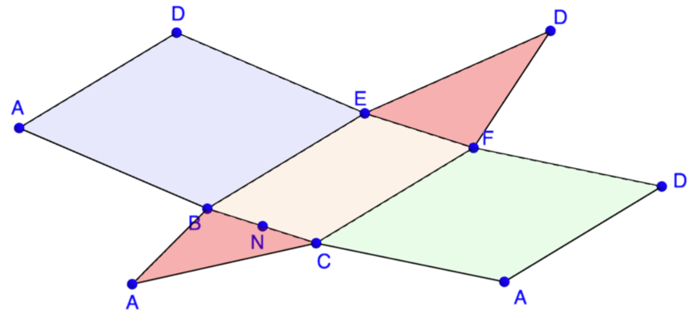


- Ask students to analyze the opened form of the solid
- Ask students how to find the surface area of the right rectangular prism

  Answer: By finding the sum of the areas of the rectangles
- Mention about the lateral faces and the bases, and state that the surface area of the right prism is the sum of the areas of the bases and the lateral faces
- Ask students how to find the surface area of a cube with edge a units

  Answer: $\boxed{6a^2}$
- Ask students how to find the surface area of a triangular prism

  Answer: By finding the sum of the areas of three rectangles and two triangles as shown below:



- At this step, it may be useful to use prepared activities in GeoGebra

  Example: https://www.geogebra.org/m/Z39w5RnP

- Ask students to discuss different cases when the base triangle is a right triangle, isosceles triangle, equailateral triangle, and scalene triangle

Volume of a Right Prism by using GeoGebra

- In this part, students will explore the volume of a right prism by using ICT tool, GeoGebra. Using technology will enhance students' understanding and engagement while preparing them for a technology-driven world.
- Ask students to go https://www.geogebra.org/m/HfF966xp , and set

  $\boxed{a = 1, b = 1, c = 1}$

- Ask students to increase the values of a, b, c randomly, and observe what happens
- Mention that the volume of a rectangular prism is the number of unit cubes, and can be found by multiplying the base area and the height of the prism
- Ask students to set a, b, and c equal to each other and discuss how to find the volume of a cube
- Here is another activity link: https://www.geogebra.org/m/M6EyxZQG

Activity

Designing a Greenhouse with Prisms by using GeoGebra

- In this activity, students are expected to apply geometric principles by designing a greenhouse using prisms in GeoGebra. They will need a graph paper and pencil. The activity will take 2 class periods (45 minutes each).

  The first period: Introduction and Initial Design

- Discuss the use of prisms in greenhouse structures
- Show examples of greenhouses with different prism shapes
- Ask students to sketch initial greenhouse designs using prisms (triangular, rectangular, hexagonal)
- Encourage students to think about how different prism shapes can optimize light and space

  The Second Period: GeoGebra Modeling

- Ask students to create 3D models of their greenhouses in GeoGebra
- Ask students to calculate the volume and surface area of their greenhouse designs
- Make adjustments based these calculations to ensure efficient use of space and materials
- Evaluate students based on the accuracy and creativity of their designs, their ability to use GeoGebra, and their geometric calculations.

  Extension Activity

- For advanced students, suggest an extension activity where they design a greenhouse with multiple types of prisms and analyze the energy efficiency and insulation properties of theis designs.