Necatibey Eğitim Fakültesi Elektronik Fen ve Matematik Eğitimi Dergisi
Cilt 17, Sayı 1, Haziran 2023, sayfa 174-210. ISSN: 1307-6086
Necatibey Faculty of Education Electronic Journal of Science and Mathematics Education
Vol. 17, Issue 1, June 2023, pp. 174-210. ISSN: 1307-6086

Research Article

Enhancing Pre-Service Teachers' Technological Pedagogical Content Knowledge (TPACK) through the Learning by Design Framework: A Fink Taxonomy-based Study*

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Received : 09.03.2023 Accepted : 29.06.2023

https://doi.org/10.17522/balikesirnef.1262115

Abstract – This study aimed to develop Technological Pedagogical Content Knowledge (TPACK) through the use of the Learning by Design (LBD) framework in a teaching process for pre-service teachers. During a 12-week period that included both teaching and data collection, 19 pre-service teachers produced 10 unique instructional materials. TPACK levels and self-confidence were assessed using scales and qualitative data from interviews, with the Fink Taxonomy used to analyze the interviews and determine the significance of the LBD-TPACK teaching process in terms of learning outcomes. The results showed a significant increase in pre-service teachers' TPACK scores and TPACK self-confidence scores after the teaching process ($\alpha=0.05$, $p=0.00$). Qualitative data supported these findings, demonstrating that pre-service teachers had achieved significant learning outcomes by the end of the process. It is recommended that conducting comparable research across diverse teaching fields and larger sample sizes would lead to more robust and generalizable findings.

Key words: Teacher training, TPACK, learning by design, fink taxonomy, instructional material

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* This study was produced from the data obtained within the scope of the corresponding author's doctoral dissertation under the supervision of the second author approved by Balıkesir University, Institute of Science in 2019.

Introduction

The effective delivery of quality education in modern times requires teachers to possess not only knowledge of the subject matter they teach but also teaching skills. Teachers need to be equipped with the necessary competencies to navigate and utilize various technological tools to enhance teaching and learning. There is an increasing expectation that teachers integrate educational technologies into the teaching process (Johnson et al., 2014), making the technology competency of pre-service teachers crucial (Sang et al., 2010). Research has consistently shown that teachers who receive high-quality training are critical to the educational system (Artz & Armour-Thomas, 1999). However, defining the concept of a "qualified teacher" from a single model or perspective may have limitations, such as overlooking the importance of technology competency and pedagogical skills. To address this, the Technological Pedagogical Content Knowledge (TPACK) framework has emerged as a fundamental concept in reshaping teacher training programs in many universities (Abell, 2008; Mishra & Koehler, 2008). TPACK is a teacher knowledge model created by Mishra and Koehler (2006) that integrates the Pedagogical Content Knowledge (PCK) concept developed by Shulman (1986) with technological knowledge accumulation to provide a comprehensive framework for teacher training.

The Technological Pedagogical Content Knowledge (TPACK) framework is a pioneering theory aimed at determining teachers' knowledge of how to effectively integrate technology into teaching. Within this framework, teachers articulate their requirements to become effective educational technology users. According to the TPACK model, effective use of technology in education requires a superior level of technological knowledge, pedagogical knowledge, and content knowledge. Moreover, the model emphasizes the commonalities among these knowledge types (Mishra & Koehler, 2006; Polly, 2011). The model proposes that developing the TPACK of pre-service teachers is crucial for successful teacher education, and rich educational experiences are necessary for this to occur (Mishra & Koehler, 2006). These experiences facilitate an understanding of the shared impacts of technology and pedagogy while pre-service teachers learn particular content. Learning experiences that focus solely on one or two of these knowledge components, without considering the common effects of technology, pedagogy, and content knowledge, are inadequate to support the technology integration knowledge and skills of pre-service teachers (Polly & Orrill, 2016).

Within the scope of this study, a teaching process was conducted to develop pre-service teachers' TPACK, and efforts were made to ensure they played active roles in all processes as required by the TPACK model. This included questioning, researching, discussing, performing self-assessment, and making corrective decisions about their work. To ensure this occurred, Learning by Design (LBD) principles were used. The data obtained from the study revealed that a dynamic teaching process occurred, where pre-service teachers made their own choices, decisions, and actively carried out their roles as both teacher and learner in coordination. The variations in TPACK levels of pre-service teachers were investigated with data obtained at the end of the process, and significant learning outcomes from this learning experience were researched.

In line with this, the study sought answers to the following questions:

1. Is there a significant change in TPACK levels and TPACK self-confidence levels of pre-service teachers between the start and end of the material development process?
2. What are the opinions of pre-service teachers about the teaching process and materials developed and do these opinions include significant learning outcomes?

Development of Technological Pedagogical Content Knowledge of Pre-service Teachers

Based on research, it is recommended that teachers receive basic technological education prior to entering service and that education faculties are the most effective and cost-efficient organizations to provide this training (Hur et al., 2010). In most teacher training programs, pre-service teachers are required to take lessons in education technology or technology integration at the beginning of the program. These lessons provide opportunities for pre-service teachers to learn and develop certain content by utilizing teaching technologies. Additionally, applied lessons are often combined with these education technology courses, allowing pre-service teachers to observe the integration of education and technology in real-world environments.

Education faculties should integrate technology with teacher training programs in an effective way that is open to innovation. Within the system, a way for teachers to gain competence in terms of TPACK requires education faculties to cultivate pre-service teachers who know how to use technology (Sang et al., 2010).

Research on teacher training programs has shown that there are many obstacles to the effective integration of technology into classes by pre-service teachers. There is a significant difference between technology education in teacher education programs and technology integration in professional life (Sang et al., 2010). Additionally, differences encountered by pre-service teachers during teacher training programs can lead to the development of mistaken beliefs about how to develop technology-based teaching and learning (Ottenbreit-Leftwich et al., 2010). These mistaken beliefs can be misleading for both the teacher themselves and their students during their professional lives. Despite pre-service teachers having adequate technological knowledge, integration efforts will fail if they do not have accurate pedagogical beliefs (Ertmer, 2005).

Pre-service teachers generally have knowledge about the basic use of technological tools; however, they often struggle to combine this technological knowledge with pedagogical implementation (Byker, 2014).

In teacher preparation programs, it is important for pre-service teachers to learn how to successfully integrate technology (Öztürk, et al., 2020). One primary way for this to occur is by involving pre-service teachers in activities that promote academic development with technology support in a planned manner throughout the duration of the program. The preparation of pre-service teachers for technology integration requires opportunities to observe models and apply knowledge in real or similar environments (Golas, 2010; Öztürk, et al., 2022; Tondeur et al., 2011).

In order to ensure the necessary development of TPACK required to manage and run teaching processes supported by information and communication technologies, pre-service teachers need to be directly included in similar situations in real learning environments and complete similar tasks (Koehler & Mishra, 2005a). According to the approach called "learning technology by design" by Koehler and Mishra (2005b), designing teaching materials and actively using them within the teaching process provides an opportunity for pre-service teachers to apply the knowledge and skills they will use during their professional lives. As teaching materials encompass all three basic knowledge types (technological knowledge, pedagogical knowledge, and content knowledge) in terms of TPACK, they offer an effective learning environment for observing relationships and integrating these knowledge types.

Learning by Design Approach in TPACK Development

It is possible to produce original content through manual activities for the development of the basic structure of TPACK. Learning technology and pedagogy is possible by designing teaching technologies and working in small cooperative groups to develop solutions in terms of technology for real pedagogical problems (Koehler et al., 2007). In the literature, learning approaches called design-based learning or learning by design (LBD) ensure the discovery of significant variables and relationships in the natural environment of the class (Koh &

Divaharan, 2013). Design activities offer important opportunities that ensure a broader understanding of the relationship between content, pedagogy, and technology by the participants. Learning-by-design work plays an effective role in removing misconceptions and completing significant learning (Koehler & Mishra, 2005a; 2005b; Kolodner et al., 2002).

The LBD approach provides significant opportunities for pre-service teachers to develop their technological knowledge. It involves a cooperative process where pre-service teachers learn through experience by making decisions and applying them. Within this systematic process, pre-service teachers need to communicate with both peers and lecturers, share ideas, and engage in cooperative work. The basic principles of LBD include the following:

- Pre-service teachers should be involved in a dynamic scientific process that involves asking questions, discussing responses, conducting research, having active discussions, and applying what is learned.
- Pre-service teachers should be guided to identify and confront misconceptions and learn new concepts.
- Pre-service teachers should be encouraged to establish connections between available knowledge, accumulation, and experiences with scientific data, theories, concepts, and laws.
- Pre-service teachers should be motivated to want to learn, and they should be provided with a thorough explanation of what learning entails and what is required for learning to occur.
- Decision-making, defending decisions, discussions, and identification of new problems should integrate real-life knowledge with scientific information (Kolodner et al., 2003).

A variety of research has been conducted on the use of LBD in higher education institutions and its effects (Alayyar, 2011; Lu et al., 2011). The common aim of these studies is to enhance technology cognition through LBD, and the results indicate that this aim has been achieved. The findings from these studies demonstrate that teaching processes completed within the scope of LBD activities enhance the TPACK levels of pre-service teachers.

Lu et al. (2011) and Kolodner et al. (2002) proposed a learning-by-design model with five stages to ensure TPACK development during the education of pre-service teachers based on the LBD model:

Determination of targets: In this process, pre-service teachers are given information about what can be included in design tasks. Generally, this task is to design an educational product with technology or shape topics in response to real-life problems with the aid of technology. Model lessons are designed, and pre-service teachers are directly included in the implementations in these lessons. These implementations include in-class discovery activities and debate sessions. Pre-service teachers research topics about how to effectively use technology for teaching purposes, and debate the results in the class environment. With the aim of recognizing problems, reading activities may be beneficial for these activities.

Making the design plan: In this step, pre-service teachers undertake special tasks related to their project. They work independently or with teammates to plan an educational product or solution design. Linked to the requirements of the project, pre-service teachers decide on their design plans by determining the target audience, topic content, making selections, and analyzing the teaching strategies and technology to be used. Project teams organize sharing and discussion activities to communicate draft ideas to teammates.

Designing and producing teaching materials: Pre-service teachers begin to design and create within the framework of the plans for projects/materials involving educational products or solutions. In this process, it is important to work in cooperation. Lecturers and other pre-service teachers share opinions and constructive feedback continuously. Mini scenarios are created about solutions to problems using integrated pedagogy, content knowledge, and technology. The main focal point in this process should be the use of technology for teaching purposes.

Trialing the material: Pre-service teachers apply their designs in a real teaching environment. Other pre-service teachers in the role of the target audience have the opportunity to use and investigate products. The trial process again ends with active feedback and recommendations. All pre-service teachers and lecturers investigate and debate the suitability of the teaching solutions in depth. The basic focus for all participants should be to ensure awareness of the relationships between content, pedagogical knowledge, and technology.

Analysis and interpretation of results: In this process, pre-service teachers are requested to express and explain their design experience with written reports, interviews, and diverse reflection forms. Within the scope of design studies, learning, strong and weak aspects are explained, new design plans are recommended based on experience, and connections are made between the experience of technology use in the lesson with use in future careers. Lecturers and other pre-service teachers provide written feedback, and it is important to reach a common view about class applications and teaching methods by discussing these. This discussion and feedback will create a basis for pre-service teachers to be able to reflect on the common effects of pedagogy, content knowledge, and technology in teaching activities when they begin service (Lu, 2014).

As can be seen within the scope of the principles stated above, it is necessary for pre-service teachers to work in cooperation with peers and lecturers, and to determine and discuss ideas and outcomes. All processes should be repeated until final materials emerge, desired targets are reached, and all mistakes are eliminated.

LBD offers the opportunity for first-hand experience of seeing theories and ideas in practice, developing skills, sharing ideas, and seeing the outcomes of changes made. LBD, allowing the opportunity for in-depth analysis of the results of actions, ensures the creation of constructive learning environments (Han & Bhattacharya, 2001). LBD learners have the chance to have rich experiences and understand the relationships between content knowledge, pedagogy, and technology (Koehler & Mishra, 2005a; 2005b; Koehler et al., 2004). Design activities ensure the completion of concrete, understandable, and significant learning processes to resolve misconceptions and to complete inadequate information.

In a variety of studies performed with the aim of acquiring technology integration knowledge to be applied in class, pre-service teachers worked in groups to search for solutions to problems related to teaching technologies, and successful results were obtained (Alayyar, 2011; Baran & Uygun, 2016; Koehler et al., 2004; Koehler et al., 2007; Koehler & Mishra, 2005b; Jang & Chen, 2010; Johnson, 2012).

Baran and Uygun (2016) defined the steps necessary to ensure the TPACK development of pre-service teachers within the LBD framework. In line with these steps, they stated that the LBD process should be followed as listed below for TPACK development of pre-service teachers:

- Brainstorming about design
- Design of technology-supported lesson material
- Investigation of design samples
- Investigation of conceptual framework
- Research about information and communication technologies
- Reflection on design experiences
- Application of design in a real environment

• Cooperation with design teams

Fink Taxonomy

Fink Taxonomy was used as a conceptual framework for the analysis of qualitative data in the research. Fink taxonomy provides a guide to the learning content required for significant learning to occur.

Bloom's Cognitive Taxonomy is one of the references most commonly used by teachers when planning what acquirements students will learn from teaching or how to effectively instill students with acquirements. This taxonomy comprises six hierarchical steps (remembering, understanding, applying, analyzing, evaluating, and creating) (Bloom, 1956).

According to Fink (2003), this taxonomy which has been used for a long time with positive outcomes is very important. However, it was emphasized that there were a range of difficult learning types emerging with Bloom's taxonomy from the secondary education level and that it was important to access these learning types in line with changing paradigms and needs. For example, learning to learn, leadership and environmental adjustment skills, ethics, communication skills, tolerance and adaptability to change skills, etc. are learning types that are outside the cognitive field and in fact cannot be explained by cognitive learning. This situation revealed the need for a new learning taxonomy with broader meaning (Fink, 2007; Rama & Charles, 2013; Stanny, 2016).

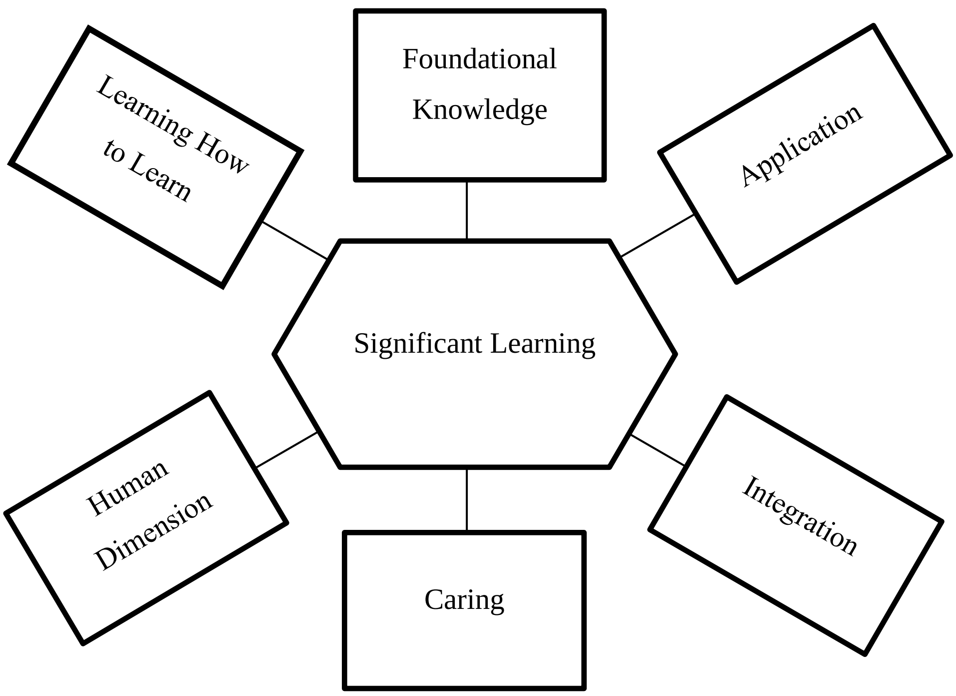

Figure 1 Learning areas and significant learning correlations (Fink, 2003, pp.10)

Fink (2003) proposed some changes were required in the learner for learning to occur and stated that these changes could be used to determine outcomes of significant learning processes. He categorizes these changes as shown in Figure 1.

Foundational Knowledge: The basis of teaching is that the student needs to know something. Knowing represents understanding and recall skills for certain knowledge and ideas by students when stated generally in accordance with the Fink Taxonomy. Currently, it is important that people have some valid basic knowledge about science, history, literature, geography, and the world they live in. Additionally, it is necessary to understand the major ideals or perspectives (e.g., what is/is not evolution, what is/is not capitalism, etc.).

Application: In addition to learning concepts, rules and ideas, students learn by being active within intellectual, physical or social activities. The application step is an important component to complete processes in a variety of forms of thinking (practical, critical, creative, etc.). Additionally, teaching of certain skills (playing piano or communication skills, etc.) and how to complete complicated projects occurs in this stage.

Integration: When students see and understand the connections between different information, it means they have obtained an important and valuable learning outcome. Sometimes, they may create connections between certain ideas, between people or different processes in life (daily life, academic life, working life, etc.).

Human Dimension: When students learn important information about themselves or others, this situation provides the opportunity for more effective communication. They discover the personal and social effects of what they have learned. Students can learn to know themselves through information learned or paths followed in learning. Additionally, this situation provides a perspective about the individual traits they wish to have in the future. Understanding others may allow understanding of the reasons for their behavior and students acquire effective communication skills as a learner.

Caring: Sometimes a new learning experience changes the degree of importance that students attach to something. These new feelings, areas of interest or values may be reflected externally. These reflections are an indicator that students care more, or differently, about something compared to before.

Learning How to Learn: During lessons, students may learn things related to their own learning process. They may learn how to learn better and more easily, how to complete research procedures, and how to manage their own learning processes. Learning all these forms the basic structure of learning.

To assist in clearer observation of learning outcomes in learning areas, the indicative verbs and behavior varieties are shown in Table 1.

Table 1 Fink Taxonomy indicative verbs

Dimension	Behaviors	Indicative verbs
Foundational Knowledge	Understanding and recall	Name, list, describe
Application	Critical, creative, and practical thinking: problem-solving	Analyze, interpret, and apply
Integration	Ability to make connections between ideas, topics, and people	Identify and associate
Caring	Ability to determine the feelings, ideas, and values of people, making changes to these	Reflect and interpret
Human Dimensions	Learning new things about the self, changing yourself; ability to understand others through interaction	Reflect and assess
Learning How to Learn	Learning to ask and answer questions; being a learning with self-direction	Criticize, analyze

There is no stage between the dimensions in the taxonomy; it is necessary to include all dimensions in the process for significant learning to occur. It may not be very easy to reveal learning areas like the learning how to learn and human dimension at all times. However, the important thing is to include learning areas at maximum levels in the teaching process (Fink, 2003; Robinson, 2009).

Method

Research Design

The research used both qualitative and quantitative data with an explanatory design from the mixed methods designs. The mixed model does not just simply combine qualitative and quantitative methods but involves comprehensive integration studies using the strong aspects of these methods to support each other. The mixed method pattern is used to answer research questions which cannot be answered with a single paradigm, especially in research based on education technologies. In explanatory mixed method research, qualitative data is collected and then used with the aim of explaining or supporting quantitative data (Creswell & Plano Clark, 2011). This pattern is used to determine the TPACK development of pre-service teachers at the end of the process and to determine whether learning outcomes were significant learning outcomes according to the Fink Taxonomy or not.

Participants

The study group for the research comprised 19 pre-service teachers attending the third year of the Secondary Mathematics Education department in a state university in the Marmara region of Turkey during the fall semester of the 2016-2017 educational year. The chosen pre-service teachers had not received any teaching material development lessons before and had no experience related to computer-supported teaching processes. With these known features of pre-service teachers, they were chosen with the targeted sampling in line with the aims of the research. Of the pre-service teachers, 4 were men and 15 were women.

Data Collection Tools

To determine the TPACK levels of pre-service teachers, at the start and end of the semester the "Technological Pedagogical Content Knowledge" scale developed by Schmidt et al. (2009) was used as the pre-test-post-test. The scale was translated to Turkish and adapted for mathematics by Dikkartın Övez and Akyüz (2013) and had Cronbach's alpha reliability coefficient of 0.91. The TPACK developed by Schmidt et al. has a 7-factor structure. These factors comprise technological knowledge, pedagogical knowledge, content knowledge, technological pedagogical knowledge, technological content knowledge, pedagogical content knowledge, and technological pedagogical content knowledge. However, basic components factor analysis by Dikkartın Övez and Akyüz (2013) gathered these factors under 4 headings of technological knowledge, mathematical knowledge, mathematic teaching knowledge, and technologic integration in mathematic teaching knowledge. These factors and relevant items were used without change as the study was completed with pre-service teachers and focused directly on mathematical knowledge. The items on the scale are answered with five-point Likert responses: completely agree (5), agree (4), undecided (3), disagree (2), and completely disagree (1). The highest points that can be obtained on the scale are 135, with the lowest points of 27.

To determine whether pre-service teachers in the research were confident in themselves in terms of TPACK competencies, the "Technologic Pedagogic Content Knowledge Self-Confidence Scale" developed by Graham et al. (2009) and adapted to Turkish by Timur and Taşar (2011) was used. The scale comprises four dimensions; technological pedagogical content knowledge (8 items), technological pedagogical knowledge (7 items), technological content knowledge (5 items), and technological knowledge (11 items). The scale contains a total of 31 items. For the scale in general, the Cronbach's alpha reliability coefficient is 0.92. The highest points that can be obtained from the scale are 186, with the lowest point of 26.

The scale uses 6-point Likert-type responses of I am fully confident (6), I am mostly confident (5), I am partly confident (4), I am somewhat confident (3), I am a little confident (2) and I am not confident (1). As an exception, five items (items 16 to 20) are rated with I don’t know this type of technology (0). As pilot studies for the scale by Timur and Taşar (2011) were performed with science and technology pre-service teachers, the expressions “science topic” and “science activities” in two items (item 2 and 4) were changed in line with experts’ opinions to “mathematic topic” and “mathematic activities” in this study. Apart from this, the scale was used without changes.

With the aim of identifying the thoughts of pre-service teachers about the process, semi-structured interviews were held. When preparing the interview questions, the items about observable behavior from the TPACK scale and TPACK self-confidence scale were used. With the aim of determining opinions, pre-service teachers were asked the following questions:

Q1- Do you think the material development activities you carried out during this course have contributed to your knowledge? If yes, what have you gained from it? Additionally, how has this process changed you?

Q2- What contributions did you make to the group during the working process? What were the specific tasks or projects that you completed?

Q3- Is it essential for a teacher to possess knowledge of developing instructional materials when looking at the process as a whole? Which stages of the material development process do you feel confident in? In which areas do you consider yourself particularly strong?

Q4- How would you react if you had a classroom equipped with all the necessary hardware for teaching technologies? Would this situation make you nervous or intimidated?

Q5- If you had to learn a technology that you have never encountered before, what steps would you take to be able to learn it successfully?

Q6- What considerations do you keep in mind when applying your technology and instructional material development knowledge to your classes? For what purposes do you use them? How do you determine these objectives?

Q7- What are the characteristics of a good instructional material in your opinion? What steps do you take to develop a material that possesses these characteristics?

Q8- What do you think is the connection between teaching materials and fostering mathematical thinking and instilling this mindset in students? What can you do to establish or strengthen this connection?

The questions on the interview form were shaped by receiving opinions from two different lecturers who experts in the fields of teaching technologies and mathematics education were.

Teaching and Data Collection Process

The content and activities planned according to weeks are listed below:

Introduction, Organization and Pre-Test Application: In the first week of the semester, pre-service teachers were given a brief explanation of the lesson content and information about work that would be completed during the semester. The pre-service teachers were given the printed technological pedagogical content knowledge scale and technological pedagogical content knowledge self-confidence scale and answered them in order to collect pre-test data.

Investigation and Discussion of Theoretical Topics: In the second week of the lesson, the topics of teaching technologies, teaching materials and principles of preparing teaching materials were communicated to the pre-service teachers by the researcher with the explanation method.

Theoretical topics were dealt with according to the following list:

- Communication and interaction in learning
- Teaching technologies
- Development process for teaching material
- Process components and basic principles.

In the discussion environment created in the class, pre-service teachers shared their own ideas about these topics and mentioned previous work they had performed about developing teaching material. At the end of the lesson, mathematics education material found on the Education Information Network (www.eba.gov.tr) offered by the Ministry of National Education General Directorate of Innovation and Education Technologies was investigated. Pre-service teachers shared their ideas about the material within the scope of basic principles that teaching materials should have, and a discussion was held.

In the 3rd week continuing investigation of theoretical topics, the importance of computer-supported education, varieties of implementations in computer-supported education and technologic pedagogic content knowledge topics were investigated. In the process after this, pre-service teachers formed their own design groups and were requested to design teaching material.

Creating Design Groups and Determining Acquirements from the Materials: Pre-service teachers formed two-person working groups with friends of their own choosing. As there were 19 pre-service teachers actively continuing with the lesson, there were 9 two-person groups, and 1 pre-service teacher chose to work alone.

Pre-service teachers were fully free to choose in relation to topics like the content, form, technologies used, materials, and implementations for the material they would design. However, in the name of ensuring integration between groups during this process, the preparation stages for materials were reported. They were requested to write these reports in accordance with the ADDIE (Analysis, Design, Development, Implementation, Evaluation) (Aldoobie, 2015) stages for general design models within teaching design models.

Creating Design Plans and Sharing Ideas: At the end of the sixth week of the lesson, all groups had completed the analysis and design stages of the material development process and shared their design plans in the class environment. Pre-service teachers criticized their colleagues about topics like how the topic will be presented, whether the aim of the material is teaching or habituation, the devices used, the basic structure of the flowchart, target audience, and readiness. Attention was drawn to basic elements that require attention in the development stage based on the criticisms and the design plans were revised. In this direction, sample flowcharts prepared by teacher candidates are presented in Figure 2 and Figure 3 below:

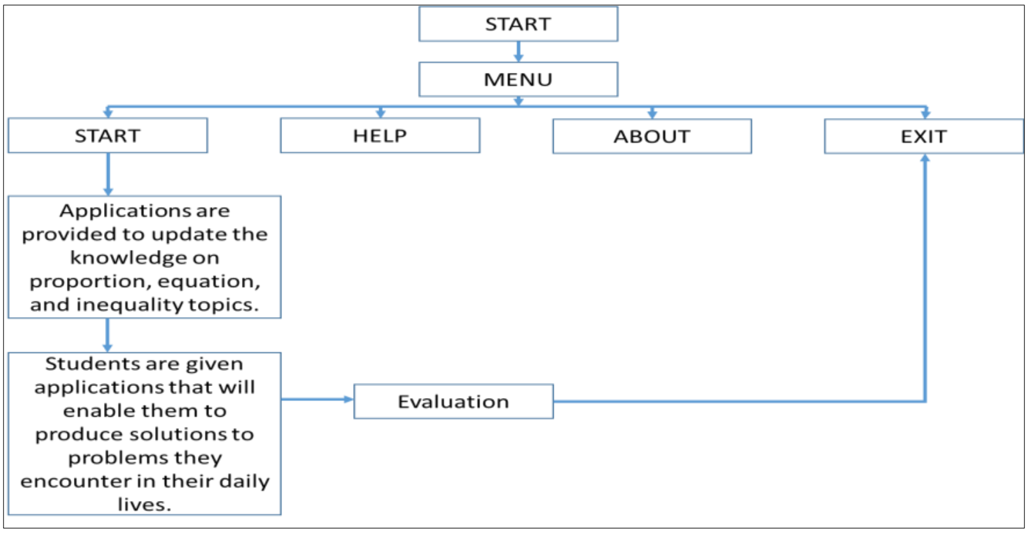

Figure 2 Flowchart of the material developed by Group 8

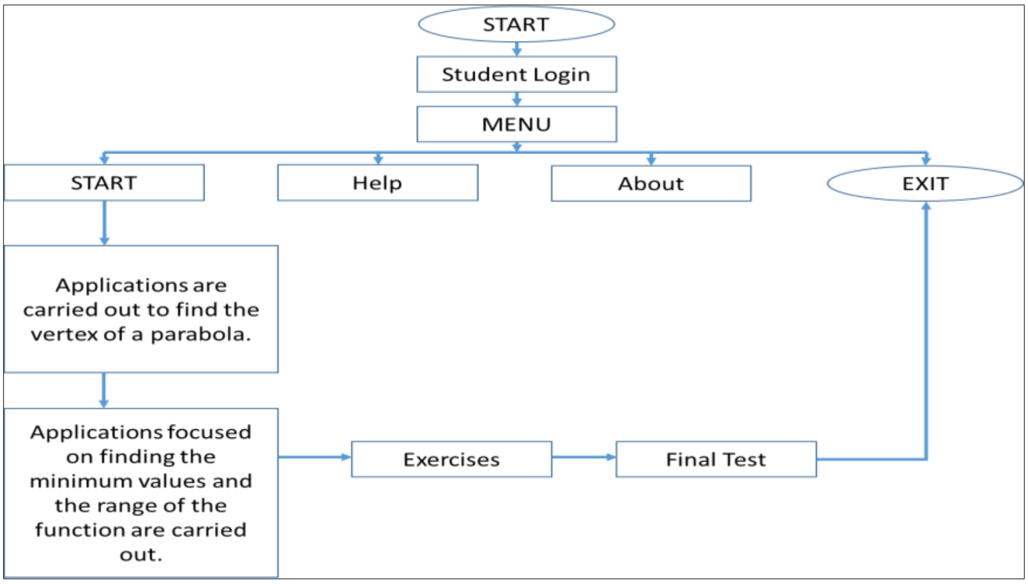

Figure 3 Flowchart of the material developed by Group 5

<u>Development of Material, Analysis and Presentation of Results</u>: In the second half of the semester, the presentation of material, interpretation, identification of strong and weak aspects, and redesign in line with these continued. In the name of ensuring all students were active during the process, criticism and evaluation of material continued outside of class. To ensure this situation, pre-service teachers made video recordings of material presentations and uploaded these videos to a private group on the social sharing network of Facebook. Pre-service teachers had the chance to investigate and criticize each other's materials on this platform outside of class.

Pre-service teachers have periodically presented the developmental stages of the instructional materials they have prepared to their peers during the course. These presentations continued with active feedback in a mutual discussion. After each presentation, teacher candidates evaluated their peers' designed materials using an online evaluation form. The main criteria listed below were taken into consideration in this evaluation form (Kaya, 2006):

1- Evaluations Related to the Content of the Material: Evaluations related to the achievement the material is intended to provide, the content of the subject matter, and the presentation method of the topic.

2- Evaluations Related to Inquiry Techniques: Evaluations related to the questioning and inquiry activities conducted during subject teaching in order to guide students, prevent incomplete or incorrect learning, and ensure gradual progress.

3- Ensuring Interest and Continuity: Evaluations related to the efforts made to attract students' attention and maintain their focus in order to ensure continuity of this attention state.

4- Creativity: Evaluations related to whether the material contains elements that support students' creativity or not.

5- User Control: Evaluations related to whether the material is suitable for students' use or not.

6- Feedback: Evaluations related to the effectiveness of the feedback provided by the material to the students.

7- Assessment and Record Keeping: Evaluations related to the extent to which the material has achieved the targeted learning outcomes, the assessment tools used, and the evaluation of teaching.

8- Documentation and Support Presentation: Evaluations related to support materials such as user manuals, additional resources or exercise presentations, help features, etc.

After each presentation, pre-service teachers evaluated the materials created by the presenting group using an online material evaluation form, which was shared via Google Forms and allowed for anonymous feedback. This process enabled more objective criticisms without revealing the identities of the evaluators to the evaluated group members. The researcher added the data obtained from the form as comments under the relevant posts on Facebook, and the materials were redesigned based on the revisions made in line with these comments.

Completion of Designs, Post-Test Application and Interviews: At the end of the semester, all groups revealed their final designs with weak aspects strengthened in line with the periodically continuing evaluations. The material evaluation form used during the development process was applied again to the final form of the design and necessary data were obtained to analyze the development process. Descriptions of the final materials developed by ten different working groups are presented in Table 2.

Table 2 Developed Materials' Types and Subjects by Groups

Group Number	Material Type	Grade and Subject
Group 1	Computer-Aided Application	12th Grade; Analytical Investigation of Ellipse, Hyperbola, and Parabola.
Group 2	Computer-Aided Application	12th Grade; Derivative.
Group 3	Instructional Material (Board Game)	10th Grade; Conditional Probability.
Group 4	Computer-Aided Application	12th Grade; Analytical Investigation of Ellipse, Hyperbola, and Parabola. 11th Grade; Trigonometry.
Group 5	Computer-Aided Application	10th Grade; Second Degree Functions and Their Graphs.
Group 6	Computer-Aided Application	12th Grade; Integral: Riemann sum.
Group 7	Computer-Aided Application	11th Grade; Trigonometry: Trigonometric functions and the unit circle.
Group 8	Computer Game; Scenario Study	11th Grade; Equations and Inequalities.
Group 9	Computer-Aided Application	10th Grade; Surface Areas and Volumes of Solid Objects.
Group 10	Computer-Aided Application	10th Grade; Special Quadrilaterals.

Individual interviews were completed for general evaluation of the material development process continuing during the whole semester. Interviews were recorded with the consent of the pre-service teachers interviewed and transcribed to text. Finally, the TPACK scale and TPACK self-confidence scale used at the beginning of the semester were applied again to obtain post-test data.

Data Analysis

As the study group comprised 19 pre-service teachers (N<30), nonparametric tests were used for the analysis of data. However, checks of the normality of data were completed. The Kolmogorov-Smirnov and Shapiro-Wilk tests results related to the total points obtained by pre-service teachers from the TPACK scale and TPACK self-confidence scale indicated normality, while histograms showed that data did not have a normal distribution. Item-based investigations observed that data were not normally distributed.

When analyzing quantitative data (TPACK scale and TPACK self-confidence scale data), the nonparametric Wilcoxon signed ranks test was used. The variation or not of total pre-test points obtained from the scales compared to total post-test points was checked with this test. When investigating the variation of subdimensions and items on the scales, the Wilcoxon signed ranks test was reused.

Content analysis was performed on data transcribed to text for analysis of interview data. The indicative verbs in the Fink Taxonomy (2003) were used as a guide for differentiation and coding of categories in the interviews with content analysis. In line with this, it was determined whether pre-service teaches displayed behavior related to which learning areas within the Fink Taxonomy. An example of the content analysis conducted in this direction is presented in Table 3:

Table 3 An example of a coding of an interview conducted

Codes	f	Opinions of Pre-service Teacher-1
Integration	1	*This course has added a lot to my knowledge and skills. I learned how to teach mathematics to students using technology and how to create instructional materials for this purpose. Through this course, I was able to identify the shortcomings in my materials and improve them to create more suitable materials for my students.*
Human Dimensions	0	
Learning How to Learn	0	
Caring	0	
Foundational Knowledge	1	
Application	1	

Validity and Reliability

When obtaining quantitative data in the research, we used scales that had been previously used within the scope of the theoretical framework and tested on study groups appropriate to the target audience. The Cronbach's alpha reliability coefficients of the scales were calculated in previous studies, and both scales had reliability coefficients above 0.90 (TPACK scale 0.91, TPACK self-confidence scale 0.92).

With the aim of ensuring the reliability of qualitative data, the interview data coded within the scope of the theoretical framework of the Fink Taxonomy were coded by two expert researchers. As stated by Miles and Huberman (1994), the compatibility between coding of the two researchers being above 0.70 is accepted as adequate for intercoder reliability. In line with this, the compatibility study calculated the ratio between categories that are compatible to the total number of categories and completed with data from 3 randomly chosen pre-service teachers found the reliability was 0.81. The data obtained from 3 randomly chosen pre-service teachers was recoded 6 months after the first data in the study was coded by the researcher and as a result the compatibility between the two coding was found to be 0.86.

To ensure the data's validity, this study examined previous research that utilized comparable participant groups and similar theoretical frameworks, enabling a comparison and discussion of the findings.

Results

Is there a significant difference in TPACK levels of pre-service teachers at the start and end of the material development process?

The Wilcoxon signed ranks test was used to investigate whether there was variation in TPACK levels at the end of the teaching material design process completed by pre-service teachers within the framework of learning-by-design. The descriptive data related to the variation in TPACK points of participants based on the pre-test and post-test total points on the TPACK scale are shown in Table 4.

Table 4 Descriptive data for pre-test and post-test TPACK scale

	Pre-test	Post-test
N	19	19
Mean	92.4737	114.6842
Standard Deviation	6.30140	9.30981
Minimum	85	105
Maximum	95	129

The total points obtained from the TPACK scale displayed a significant increase in the post-test. Data related to this result are shown in Table 5.

Table 5 Comparison of pre-test and post-test total points on TPACK scale

	Post-test – Pre-test
Z	-3.825
p	.000

The results obtained with the Wilcoxon signed ranks test showed a significant difference between pre-test and post-test with significance level $\alpha=0.05$ ($p=0.000$).

The Wilcoxon test results on a category basis to investigate points obtained from all subcategories of the scale are shown in Table 6.

Table 6 Total points variation for TPACK scale subcategories

	Z	p
TK – Technological knowledge	-3.834	.000
CK – Content knowledge	-3.362	.000
PCK – Pedagogical content knowledge	-3.727	.000
TPACK – Technological pedagogical content knowledge	-3.829	.000

When the points are considered separately for all subdimensions of the TPACK scale, again, the post-test points for all dimensions were observed to be higher than the pre-test points. In line with this, the completion of learning-by-design activities by pre-service teachers can be said to clearly contribute positively to TPACK development.

Is there a significant difference in TPACK levels of pre-service teachers at the start and end of the material development process?

To compare the points that pre-service teachers obtained from the TPACK self-confidence scale at the end of the material development process with points obtained at the start of the process, the Wilcoxon signed ranks test was used. The descriptive data related to points obtained on the TPACK self-confidence scale by pre-service teachers on pre-test and post-test are presented in Table 7.

Table 7 Descriptive data for TPACK self-confidence scale pre-test and post-test

	Pre-test	**Post-test**
N	19	19
Mean	97.000	134.7895
Standard Deviation	14.37977	12.05810
Minimum	70	113
Maximum	119	155

When the variation in total points obtained on the TPACK self-confidence scale are investigated, all 19 pre-service teachers were observed to have increased total points on the post-test, shown in Table 8.

Table 8 Comparison of pre-test and post-test total points for TPACK self-confidence scale

	Post-test – Pre-test
Z	-3.824
p	.000

The results of the Wilcoxon signed ranks test identified p=0.000 at significance level α=0.05 and observed a significant variation. For this reason, there was a positive significant difference in total points obtained by pre-service teachers from the TPACK self-confidence scale at the beginning and end of the material development process.

What were the opinions of pre-service teachers about the teaching process and developed material and did these opinions include significant learning outcomes?

All pre-service teachers agreed that the activities had contributed something to them. The opinions of a pre-service teacher (PST-15) regarding this topic are as follows:

> *As a result of the work, we have done during this course, I can say that I have become more knowledgeable about the internet and programs. I can now easily use programs that I used to struggle with before. My self-confidence has increased a lot. I have gained ideas on conducting research and selecting the best option that suits my work. We encountered different programs, and I can say that I will use most of them when I become a teacher in the future. This process has changed my thoughts on Information and Communication Technologies and their use in the classroom.*

Another pre-service teacher (PST -17) expressed his views as follows:

> *This course has taught me a lot, especially about how important math programs are for a teacher. I saw how helpful they are in teaching math, and I learned that using math programs can have a positive impact on the students' learning process. This has given me experience for my future career. I also learned how to explain something in a way that can be more helpful when teaching. Living in the age of technology, I understood how important technology is and how using it can be beneficial for both teachers and students…*

Direct experience of how effective the use of material within lessons and the process being shaped by peer assessment positively affected their perspective on teaching materials. A point emerging from the answers was that this process increased the self-confidence of pre-service teachers about their ability to prepare material and use technology in teaching. This result may be accepted as a marker of positive development considering they had not previously prepared any teaching material, completed any teaching designs and had not used technological resources during teaching.

When opinions of pre-service teachers about these questions are investigated, it appeared they proposed three basic topics where positive change occurred:

- Pre-service teachers stated they had the chance to learn and use new technologies which they were not aware of before due to this lesson.
- They stated they saw the importance of considering students' needs when designing material.
- They conceptualized the importance of integration of technology in the teaching process and learned what requires attention during this process.

Within the scope of these three main opinions, the record numbers for analysis of the interview data according to the categories of "acquiring information about new technologies", "considering student needs" and "technology and mathematic integration" are given in Table 9.

Table 9 Record numbers of opinions of pre-service teachers about the process

	Record numbers	%
Acquire information about new technologies	9	33.33
Consider student needs	10	37
Integration of technology and mathematics	8	29.66

The opinions of a pre-service teacher (PST-6) regarding this topic are as follows:

Before taking this course, I approached technology with prejudice. More precisely, the educational use of technology intimidated me. It all seemed like difficult and complex applications. Similarly, when we started this assignment, I had questions in my mind such as how it would be done, what do we know, what will we do, etc. However, when I started working on it, I realized that it wasn't that difficult at all. When you work on it a bit and think about it, technology is actually easy to use and worth the effort. At the end of this process, I realized that I could use technology to teach in my own classroom in the future. It really changed my perspective on technological applications in a positive way. I understood that technology could be easy, useful, and educational. After all, technology is an undeniable part of our lives today. Not knowing how to use technology as a teacher is a major deficiency. If we can *transfer what we know to students by knowing and using technology, we can see the contribution of this course in our teaching career.*

Data obtained from interviews completed with pre-service teachers underwent content analysis. The analysis determined the main categories as learning areas in the Fink Taxonomy and interviews were coded for suitability to these categories, shown in Table 10.

Table 10 Distribution of opinions according to Fink Taxonomy learning areas

	Record numbers	Code numbers
Integration	14	21
Human Dimensions	15	30
Learning How to Learn	10	12
Caring	19	60
Foundational Knowledge	18	36
Application	19	67

In order for significant learning to occur, it is important for all learning types to emerge due to the structure of the Fink Taxonomy. With the obtained findings, all learning areas were observed to emerge with changes in frequency (Figure 4).

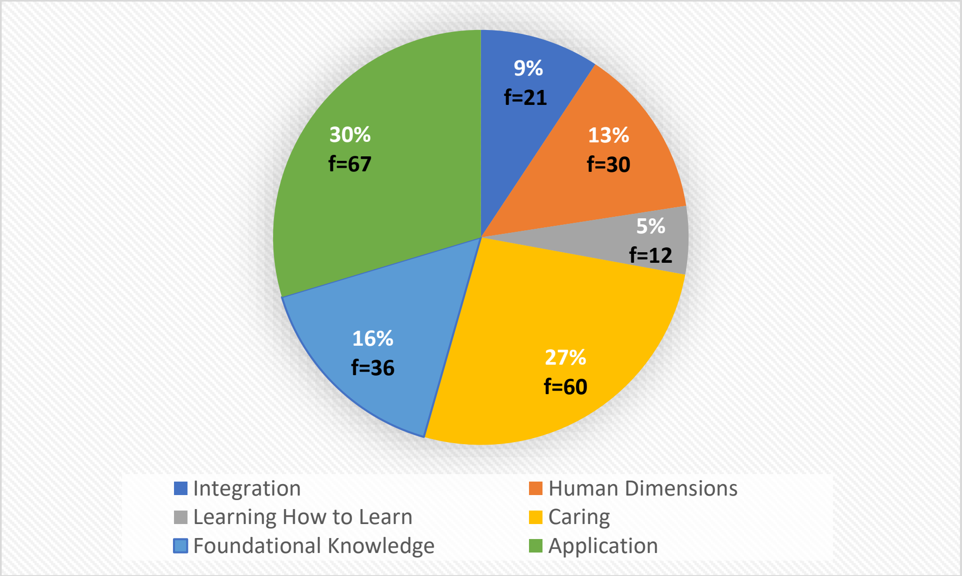

Figure 4 Percentage distribution of Fink Taxonomy dimensions

The observation of all learning areas is proof that the completed teaching process provided the basic criteria required for significant learning. For this reason, it can be stated that the variations in TPACK and TPACK self-confidence levels of pre-service teachers occurred due to significant learning experiences.

Findings and Discussions

In this study, the effects of learning-by-design activities within the scope of the teaching material development processes on the technological pedagogical content knowledge of mathematic pre-service teachers were researched. As required by LBD processes, pre-service teachers were able to work in groups with cooperation and an interactive and free special learning environment was created where they had direct said in the development of each other’s products. Within this scope, pre-service teachers were fully free to determine topics like which problem their materials would contribute to solving, what the type of material would be (physical, computer-supported application, game, etc.), how to address which target audience, what the application path would be, and which resources would be used. The basic aim was that pre-service teachers acquire experience in being able to use technologic, physical and teaching resources which are available in the environment when they begin their professional life in the most appropriate way according to student requirements and to discover the relationships between theory and practice with the aid of this experience. In line with this aim, they tested their own TPACK in applications and gained awareness of their own abilities, strong and weak aspects, and saw the results of teaching outcomes. Generally, pre-service teachers in this study had their first professional experience in the planning, design, development, application, and evaluation stages in the technology-supported teaching process.

Pre-service teachers worked in groups and shared their material with friends periodically during development and updated and revised material according to active discussions and feedback. The role of the teacher was played by the group presenting their material, while the other pre-service teachers played the role of students with each of the teaching materials presented in micro-teaching applications evaluated by all pre-service teachers. To investigate the applications in more detail and ensure time savings, lesson presentations were recorded and uploaded to social media accounts that could only be accessed by pre-service teachers in the study group (a private Facebook group) for investigation and comment by other pre-service teachers. In this way, the criticisms of pre-service teachers were recorded, and studies continued outside of lesson hours.

At the beginning and end of the teaching process including learning-by-design activities, TPACK scales were applied to pre-service teachers and the data were used to research whether the teaching had an effect on points obtained or not. In line with this, rather than focus on TPACK levels, the focus was on whether development had occurred or not. The total points received by pre-service teachers on the TPACK scale were analyzed with the Wilcoxon signed ranks paired tests and all pre-service teachers were observed to have increased post-test points compared to pre-test points ($\alpha=0.05$, $p=0.00$). This technology-supported teaching process completed within the LBD framework was observed to have a positive effect on the points obtained by pre-service teachers from the TPACK scale. This situation is parallel to the results of many studies completed previously by different researchers (Agyei & Voogt, 2012; Aygün et al., 2016; Bahçekapılı, 2011; Cavin, 2007; Chai, Koh & Tsai, 2010; Erdoğan, 2014; Figg & Jaipal, 2009; Kafyulilo et al., 2015; Karataş et al., 2016; Koh & Divaharan, 2011; Koh & Chai, 2014; Kurt et al., 2013; Maeng et al., 2013). Additionally, though several studies in the literature stated there are limited effects of teaching processes on TPACK subdimensions, findings in this study showed a change in a positive direction was valid for all subdimensions (Chai et al., 2010; Habowski & Mouza, 2014; Jang & Chen, 2010).

With the guidance of lecturers, pre-service teachers had the opportunity to complete active discussions and brainstorming activities, investigated and criticized different design examples, researched relationships between conceptual frameworks and information technologies, performed reflections, and revealed their TPACK in a real learning environment through a cooperative process where they had a say in the development of both their own designs and their colleagues' designs. When the pre-test and post-test data obtained to investigate the effect of these practices on their TPACK self-confidence is analyzed, a positive change in TPACK self-confidence levels was identified for all pre-service teachers ($\alpha=0.05$, $p=0.00$). The results of studies in the literature stating that pre-service teachers should be included in technology-supported teaching process stages support this change (Abbitt, 2011; Canbazoğlu Bilici, 2012; Karataş et al., 2016).

When pre-service teachers evaluated each other's materials, they used an online material assessment form, and each group was evaluated three times at intervals. Due to these forms, data were collected to investigate the degree to which pre-service teachers included TPACK during the material development process. Additionally, at the end of each assessment form, a section was left for pre-service teachers to write their ideas related to the materials developed, teaching, and classmates. Data obtained from this form could only be seen by the researcher, so the evaluations are presented as objective data. Without mentioning names, the research shared comments from the forms under video presentations in the social media group. In this way, continuity was ensured between active discussions occurring during lessons and the online environment. The materials and teaching process of the pre-service teachers were updated in line with the strong aspects or deficiencies mentioned. During the study lasting 12 weeks, 19 pre-service teachers working in 10 groups completed 10 different material designs. During the semester, teaching was completed using these materials three times and including their own presentations, they actively participated in 30 different teaching processes. Data obtained from the assessment forms shows that the quality of teaching material periodically increased in line with the continuing material development process, presentation in the teaching environment, discussion, and evaluation activities. Total points obtained as a result of assessments for all developed materials (including category-based points) were identified to increase compared to previous evaluations. This situation is a clear indicator of the reflection of TPACK development of pre-service teachers in the teaching process and this indicator has the quality of supporting the findings about TPACK and TPACK self-confidence development (Agyei & Voogt, 2012; Kafyulilo et al., 2015; Kurt et al., 2013; Larkin et al., 2012; Lee & Kim, 2014;).

The positive changes observed overlap with the opinions of pre-service teachers about the process. At the end of the teaching material development process, face-to-face interviews were held with all pre-service teachers. As a result of qualitative analysis of the interview data, pre-service teachers were identified to have a positive view of the LBD-based technology-supported teaching process. All pre-service teachers agreed that the teaching process contributed to their development. They frequently emphasized that they had more self-confidence about the inclusion of technology in teaching processes and preparing teaching materials for their own use. Topics emerging from the results of interview analysis including awareness of new technologies and development of their skills in being able to use these in teaching, learning the importance of technology integration and what factors require attention, and cognition about how to resolve the teaching needs of students. This situation is a clear indicator that pre-service teachers were aware of changes in themselves in becoming qualified teachers. This situation overlaps with results of similar studies and supports quantitative findings (Cavin, 2007; Erdoğan, 2014; Kafyulilo et al., 2015; Karataş et al., 2016; Kurt et al., 2013).

With the aim of investigating the opinions of pre-service teachers in more detail and interpreting results within a theoretical framework, the Fink taxonomy was used. In the literature, there is no other study investigating LBD-based teaching material development processes within the scope of Fink taxonomy learning areas. In the name of investigating whether the positive changes in TPACK and TPACK self-confidence levels of pre-service teachers were acquired within the scope of significant learning experiences or not, interview data were analyzed within the framework of Fink’s significant learning taxonomy. Findings indicate that all learning areas of the Fink taxonomy may be observed within the scope of the research process. For this reason, the LBD-based and technology-supported teaching process led to the acquirement of significant learning experiences, and it can be clearly stated that the changes in pre-service teachers are significant learning outcomes (Fink, 2007; Robinson, 2009; Rama, 2013; Stanny, 2016).

Opinions investigated within the scope of Fink taxonomy are each a representation that pre-service teachers are ready to make efforts to include their students in critical, creative and practical thinking and problem-solving processes. To ensure students gain significant learning experiences, they stated that they are aware of the need to perform studies to raise individuals who are able to create connections between disciplines and people, with self-control and free ideas. In line with this, the presence of an association between the TPACK self-confidence levels, TPACK levels and Fink taxonomy learning areas of pre-service teachers was investigated. Due to the structure of Fink taxonomy, the emergence of all learning areas is proof that significant learning occurred, while the emergence or observation of some learning areas may be more difficult than others. For this reason, the post-test points obtained on the TPACK self-confidence scale of pre-service teachers who emphasized “learning how to learn”, accepted as a statement of the importance of student-centered education and with the least record numbers among pre-service teacher interviews, were investigated. All eight pre-service teachers emphasizing this learning area were identified to have TPACK self-confidence scale points that were above the average for the group. Mann-Whitney U test results showed a significant correlation between this learning area and TPACK self-confidence points ($p=0.015$; $p<0.05$). This situation is accepted as a statement about the importance shown by pre-service teachers who trust themselves in performing effective teaching by combining technology, content knowledge, and pedagogy to raise their students to be questioning and researching individuals who learn by themselves. Additionally, for all other learning areas, including between TPACK self-confidence levels and “learning how to learn” area, there was no significant correlation identified between all Fink taxonomy learning areas with TPACK points. This situation is directly related to the small dimensions of the study group ($N=19<30$). For this reason, it is thought that similar analyses completed with larger study groups in future research will offer more significant findings.

In conclusion, due to practices, research and analyses implemented in this study, the LBD-based teaching material development process for mathematic pre-service teachers was observed to have a positive effect on TPACK and TPACK self-confidence. The learning experiences creating this effect can be clearly stated to occur as significant learning experiences within the scope of the Fink taxonomy.

Conclusions and Suggestions

All implementations within the scope of this study were completed with pre-service mathematics teachers. However, it is possible to adapt the teaching process for pre-service teachers attending other departments with similar implementations using appropriate measurement devices. Planning, developing, and running technology-supported teaching processes are important skills necessary for all teachers to develop. In order to provide this, it is possible to use LBD stages as in this study or to use different teaching approaches.

A basic point that requires attention is that the teaching environment should present similar environments to those that will be encountered by pre-service teachers in professional life. Micro-teaching practice leads to very successful results in meeting this need.

In this research, the study group comprised 19 pre-service mathematics teachers. Expanding the study group to complete more comprehensive research on similar research problems will offer more detailed findings for the generalizability of the results.

It is possible to observe the effects on other teaching areas by performing similar studies with pre-service teachers attending other departments. Expansion within this scope will offer important findings about teacher education to compare the TPACK development of pre-service teachers from different branches, and to investigate the interdisciplinary development provided by a cooperative process with different branches receiving assistance from each other.

With the condition of keeping interactions between individuals and groups at the highest levels, similar to the learning-by-design activities used in the implementation process in this research, research may be performed with all special teaching methods directing pre-service teachers toward research, problem-solving, and producing a product.

It is possible to adapt this research as in-service teacher training to investigate the technology-supported teaching process among teachers, to research TPACK levels and development and to investigate the technology-supported teaching methods and material developed. In this way, the present situation will be revealed, inadequacies will be determined if present and contributions will be made to work on taking corrective precautions.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

The authors have not disclosed any conflict of interest.

Funding

This study is not funded by any person or organization.

CRediT author statement

Okan Durusoy: Conceptualization, Methodology, Formal Analysis, Investigation, Data Curation, Writing - Original Draft. **Ayşen Karamete**: Supervision, Validation, Writing - Review & Editing.

Research involving Human Participants

This study was produced from the data obtained within the scope of the corresponding author's doctoral dissertation under the supervision of the second author approved by Balıkesir University, Institute of Science in 2019. In this context, all ethical compliance criteria have been completed.

Tasarım Tabanlı Öğrenme ile Öğretmen Adaylarının Teknolojik Pedagojik Alan Bilgilerinin (TPACK) Geliştirilmesi: Fink Taksonomisi Temelli Bir Çalışma

Özet:

Bu çalışmada, öğretim sürecinde tasarım tabanlı öğrenme (Learning by Design - LBD) çerçevesi kullanılarak öğretmen adaylarının teknolojik pedagojik alan bilgilerinin (Technological Pedagogical Content Knowledge - TPACK) geliştirilmesi amaçlamıştır. 19 öğretmen adayı, 12 haftalık bir öğretim ve veri toplama sürecine katılarak 10 farklı öğretim materyali oluşturmuştur. TPACK ve TPACK özgüven seviyeleri, ölçeklerden elde edilen nicel veriler ve görüşmelerden elde edilen nitel veriler kullanılarak değerlendirilmiştir. LBD-TPACK öğretim süreci sonunda elde edilen öğrenme çıktılarının anlamlı öğrenme çıktıları olup olmadığını belirlemek için görüşme verileri Fink Taksonomisi kullanılarak analiz edilmiştir. Bulgular, öğretmen adaylarının TPACK puanlarının ve TPACK özgüven puanlarının öğretim sürecinden sonra arttığını göstermiştir ($\alpha=0.05$, $p=0.00$). Sonuçların nitel verilerle desteklendiği ve öğretmen adaylarının anlamlı öğrenme çıktılarına sahip oldukları görülmüştür. Gelecekteki benzer çalışmaların; TPACK gelişimine yönelik etkinliklerin öğretmen eğitimi faaliyetlerine etkin entegrasyonunu sağlamak adına farklı öğretmenlik alanları ve daha büyük çalışma grupları ile yürütülmeleri doğrultusunda önerilerde bulunulmuştur.

Anahtar kelimeler: Öğretmen yetiştirme, TPACK, tasarım tabanlı öğrenme, fink taksonomisi, öğretim materyali

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