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The evaluation of technology-based course materials developed by mathematics teachers

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Abstract

The change in technology manifests itself in the restructuring of mathematics teaching and learning processes. Effective use of information and communications technology (ICT) in learning environments has gained importance. The ability to prepare technology-based course materials is currently one of the competencies of teachers. In this study, within the scope of the Erasmus+ project titled 'Math Teachers' Adventure of ICT Integration', mathematics teachers were offered an online course called 'Teaching Mathematics with GeoGebra,' which combines geometry, algebra, graphs, statistics and calculus in a single interface. It is both a dynamic geometry software program and a computer algebra system. The aim of this study is to examine the course materials developed by teachers using GeoGebra and determine the errors in their materials. The technology-pedagogy-content knowledge model was used as the framework for the content analysis. Based on the results, suggestions for both in-service training of teachers and future research were presented.

Keywords: GeoGebra; ICT; course material; technology enhanced mathematics teaching.

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1. Introduction

Considering the habits of new generation defined as 'digitally born' and the contribution of manpower and technology required in this information age to the process of learning and teaching, it can be asserted that the integration of information and communications technology (ICT) into education is necessary. Today, technology has transcended being a mere tool that supports students in terms of structuring, explaining and talking on their knowledge. Now, students learn with technology instead of learning from technology (Howland, Jonassen & Marra, 2012).

Many countries based their national education policies on knowledge and ICT, in order to integrate the rapid technological improvements into the field of education (Tezci, 2011). Educating individuals who are proficient in ICT usage is the leading requirement of contemporary education, and the concepts of education and the use of technology in education have become inseparable (Erdemir, Bakirci & Eyduran, 2009; Komis, Ergazakia & Zogzaa, 2007).

Turkey has updated its education programmes to reflect the technological improvements in the field of education and to pave the way for an ICT-supported learning and teaching environment (Milli Egitim Bakanligi (MEB) & Talim Terbiye Kurulu Baskanligi, 2013). According to the new education programmes, the main goal of education is to raise individuals who know how to reach information and who can use information and technology to find solutions to the problems they face, rather than raising individuals who receive information from only one source and memorise it (MEB & Talim Terbiye Kurulu Baskanligi, 2013). In order for the individuals to attain these attributes, first, teachers need to possess these skills and then, they need to use the materials prepared in accordance with the principles of ICT and educational technologies effectively during the learning–teaching process (Tan & Wang, 2011).

'ICT Competency Framework for Teachers' prepared by UNESCO suggests improving preservice teachers' technological literacy skills (Chai & Lim, 2011; Martinovic & Zhang, 2012). Preservice teachers must be equipped with skills like designing the learning environment effectively using technology and guiding students to use technology for educational purposes (Russell, Bebell, O'Dwyer & O'Connor, 2003). At this point, it must be stated that it is not enough to help students acquire only technical skills, as the use of technology in classroom adds new variables to teaching context and makes it even more complex (Koehler & Mishra, 2008). Thus, technology-supported teaching requires a framework which explains how to effectively integrate the ever-changing technology with the content and various pedagogical approaches.

'Technological pedagogical content knowledge (TPACK)' approach presents a structure which provides guidance on the integration of the technology appropriate for the content and pedagogical approach with the teaching process (Koehler & Mishra, 2008; Mishra & Koehler, 2006). It is based on Shulman's (1986) pedagogical content knowledge (PCK) approach, which suggests that pedagogical knowledge (PK) and content knowledge (CK) of teachers should be considered together. According to Shulman (1986), teachers should have a sound grasp of the interaction between pedagogy and content so that they could implement the strategies that could help students understand the content fully. Beyond the PCK approach, TPACK argues that teachers should understand the type of relationship between technology, pedagogy and content and should construct a new type of knowledge that transcends these three different knowledge infrastructures.

Within the scope of the TPACK approach, the competencies teachers are expected to have are given in seven categories, which are explained as follows (Mishra & Koehler, 2006):

- CK: It refers to the knowledge about a field or a subject or about their fundamental structure. It is the knowledge of teachers or preservice teachers about the subject matter that will be learned or taught.
- PK: It is the knowledge of teachers or preservice teachers about teaching approaches and which teaching approach they could use to best teach a topic. PK includes knowledge about classroom management, improving student motivation, lesson planning, and the evaluation of teaching. It also refers to being informed about different teaching methods like knowing how to design the activities in a way to help students generate constructive knowledge.
- Technology knowledge (TK): It is the knowledge of teachers or preservice teachers about standard (blackboard, book, etc.) and digital technologies (video, presentation, interactive whiteboard, educational software, etc.). Due to the rapid changes in technology (Mishra, Koehler & Kereluik, 2009) and the variable nature of technology (Koehler & Mishra, 2008), technological knowledge is continuously changing. Thus, technological knowledge adapts to new technologies and includes the ability to learn these new technologies as well.
- PCK: It is the knowledge about the teaching approach that a teacher or a preservice teacher could use to teach a subject. This knowledge is beyond being an expert in a subject or knowing only the general pedagogical principles. It refers to understanding the unique interaction between content and pedagogy.
- Technological pedagogical knowledge (TPK): It is the knowledge of teachers and preservice teachers about their technological competencies and how these competencies can change teaching. This knowledge enables teachers to understand what technology can do to reach certain pedagogical aims and to choose the most functional tool for the respective pedagogical aims. Technology makes new environments and methods accessible for teaching and facilitates the implementation of some activities.
- Technological Content Knowledge (TCK): It is knowledge about the relationship between technology and CK. Technology helps explore some new concepts and the presentation of these new concepts and thus, enables teachers to teach some content in ways that were not possible before. For example, today, students can learn about geometric shapes or angles by touching and playing with them on the screens of mobile devices.
- TPACK: It is the knowledge of teachers or preservice teachers on the technologies and teaching approaches they could use to teach a subject. It is the combination of technology, pedagogy and content.

All the types of knowledge within the scope of TPACK reflect a necessary and important part of education. However, effective teaching goes beyond each of these components (Koehler, Mishra, Akcaoglu & Rosenberg, 2013). TPACK, which represents the interactive aspect of the components as a whole, means that teachers know students learn the subject in a more meaningful way with technological devices and that teachers can combine technology with pedagogical strategies while teaching a subject (Graham et al., 2009). A teacher with TPACK can blend technology, pedagogy and CK and can use this knowledge to design effective learning experiences (Koehler et al., 2013).

It has been identified that in the last 10 years, teachers tried to have an access to the resources with original content to add variety to the in-class activities, to offer students the opportunity to study independently, and to strengthen their present teaching practices. They have also chosen to use ICT as a useful material to configure the learning–teaching processes (Gao, Choy, Wong & Wu, 2009; Hayes, 2007; Koh, 2013; Lim & Chai, 2008; Smeets, 2005; Ward & Parr, 2010). During this process, it is of great importance for teachers to have the general background in TPACK components and to use the different knowledge backgrounds they have effectively.

The present study aims to reveal the competencies of mathematics teachers in terms of TPACK. To this end, the study was conducted within the scope of an online course called 'Teaching Mathematics with GeoGebra', which is one of the outputs of the Erasmus+ project named 'Math Teachers'

Adventure of ICT Integration', numbered 2015-1-TR01-KA201-021561, and funded by the European Union. During the course, mathematics teachers were taught beginner level GeoGebra and at the end of the course, they were asked to design their own teaching materials using GeoGebra to be used during the lesson. The course materials developed by the teachers were evaluated taking the TPK, TCK and TPACK components into account; and the errors in the materials were examined. It is believed that the results of the study may help make suggestions regarding in-service teacher training sessions and the online courses to be developed in the future.

2. Method

The study group was composed of 45 mathematics teachers who were enrolled in the 'Teaching Mathematics with GeoGebra' online course. The data were the teaching materials developed by the teachers using GeoGebra within the scope of the course. Among these materials, those taken from the GeoGebra material library and those left incomplete were removed from the study. As a result, the remaining 21 materials were analysed.

Content analysis was conducted during data analysis. During the data analysis process, TPACK-based technology integration assessment rubric (Harris, Grandgenett & Hofer, 2010) was used. This rubric was obtained by making some changes on the technology integration assessment tool, which was developed by Britten and Cassady (2005) to evaluate technology integration into the lesson plans of teachers. Harris et al. (2010) developed this rubric for the use of teacher trainers to help them evaluate the lesson plans and projects developed by preservice teachers in terms of the quality of technology integration. Intercoder reliability of the rubric was 85%; internal validity (using Cronbach's Alpha) was 91%, and test–retest reliability was 87% (Harris et al., 2010).

The course materials were evaluated by two independent researchers using the TPACK-based technology integration assessment rubric with respect to TPK, TCK and TPACK domains. Although Harris et al.'s (2010) rubric included another component as 'fit', the researchers did not analyse it, since they believed the same construct was found in the TPACK domain. The highest and lowest scores in the rubric are 4 and 1, respectively. Kendall Tau_c analysis was conducted to calculate the percentage of fit between the coders. Intercoder concordance in TPK, TCK and TPACK domains were found to be at 61%, 72% and 72%, respectively. Thus, it can be concluded that the fit between the coders was good during the data analysis process.

3. Findings

The average of the points given for each material by the experts for TPK, TCK and TPACK components was taken and the average points were considered as material points. The materials with 3 points or higher were categorised as 'high'; while the materials with 2 or 3 points and those with 1 or 2 points were categorised as 'moderate' and 'low', respectively. The following table shows this categorisation.

Table 1. Number of materials based on average points

	Number of materials based on average technological pedagogical knowledge points	Number of materials based on average technological content knowledge points	Number of materials based on average technological pedagogical content knowledge points
Low ($1 < x < 2$)	6	5	4
Moderate ($2 < x < 3$)	11	6	13
High ($3 < x < 4$)	4	10	4

Eleven of the materials developed by the teachers were at moderate level in TPK domain, while six materials did not meet the requirements of this domain and thus were found to be at low level. On the other hand, four materials were found to be at high level as they were in accordance with the features required by the TPK domain. When the average points in the TCK domain are concerned, it can be said that ten materials met the requirements of this domain at high level, whereas five materials were found to be insufficient in terms of TCK and thus were at low level. Six materials, on the other hand, were at moderate level with respect to the features required by this domain. While the average points in TPACK domain indicate that 13 materials were sufficient at moderate level in terms of TPACK, it was seen that four materials could not meet the requirements of this domain and four materials met adequate requirements and thus were at high level.

While the highest number of materials at low level was found in the TPK domain, the highest number of materials at high level was found in the TCK domain. The most-frequently encountered errors in the materials that fell into the 'low' category were presented under the headings below for each domain.

3.1. Technological pedagogy knowledge errors in the materials

Technological pedagogy knowledge is defined as the appropriate use of technology by the teacher in accordance with the pedagogical aims. The errors evaluated in this respect can be interpreted as breaking the pedagogical rules due to some technical problems in the material. Within the scope of the study, the most frequently encountered error pertaining to technological pedagogy knowledge is including the codes in the algebra window in the material despite not using them at all.

As seen in Figure 1, leaving the code windows showing the steps used in the materials design process, open in the algebra window on the left part of the screen, cause students using the material to click on these codes and undo the material development steps, which results in a nonsense shape. This means that the material cannot achieve its purpose in the learning–teaching process and students may experience misconceptions.

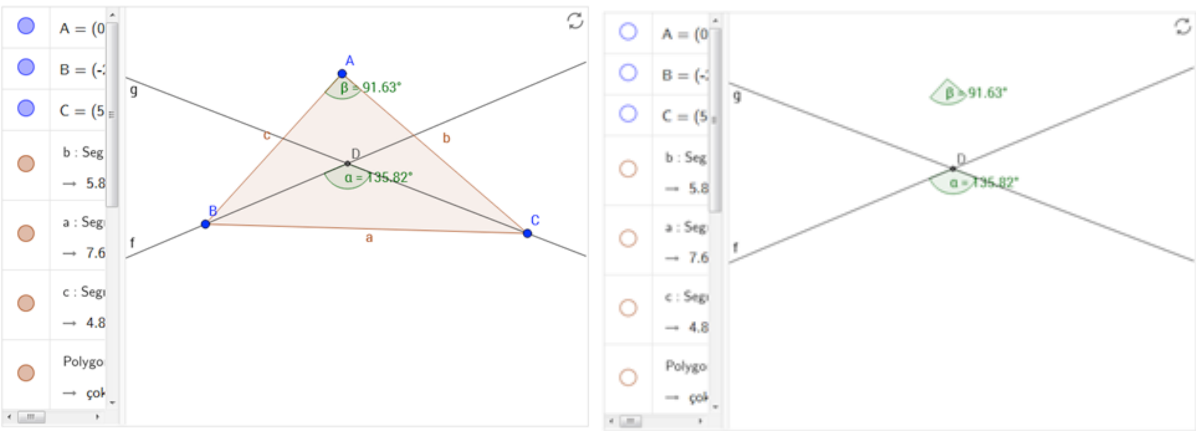

Figure 1. A sample error for technological pedagogy knowledge

This problem, which is based on teacher's lack of technological knowledge, leads to the inclusion of unnecessary information in the material, which is a pedagogical error. Thus, the materials in which the codes in the algebra window are left open without a reason were evaluated as low-level materials in terms of TPACK.

3.2. Technological content knowledge errors in the materials

TCK is defined as teachers' knowledge on the relationship between technology and CK. Technological content errors are evaluated as the errors made by teachers concerning the use of GeoGebra effectively while teaching the content. The error encountered most frequently in this group is that in the course materials on exponential and logarithmic function, the variable indicating the base of the function can take the values of 0 and 1 both in algebraic expression and in the graphic of function, which is mathematically impossible.

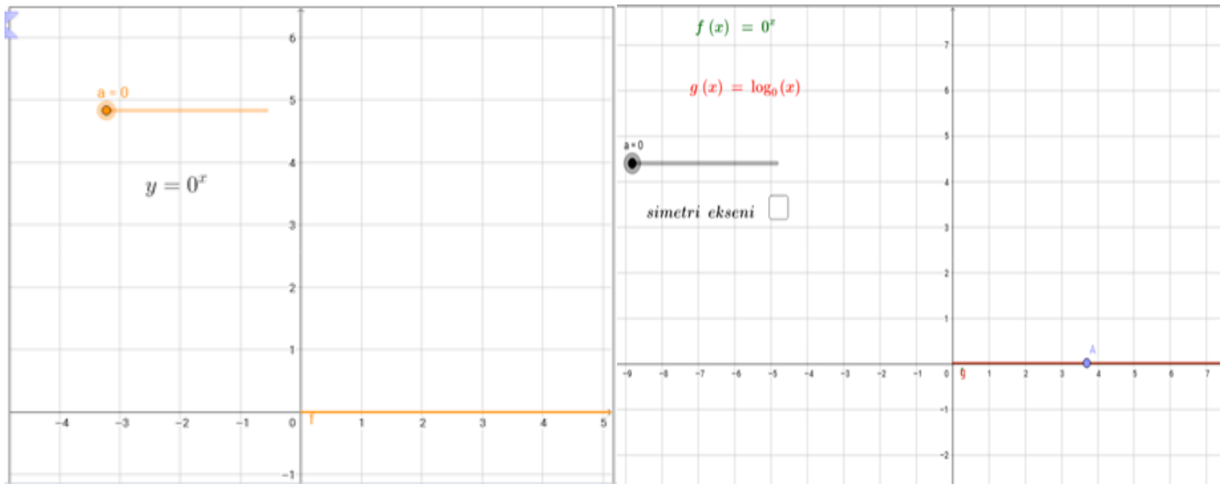

Figure 2. A sample error for technological content knowledge

Figure 2 shows the course materials with this type of error. The basis of the error is teacher's lack of knowledge in technology domain. The teacher had a problem in creating the slider which helps to change the value the exponential and logarithmic function base takes and could not make the slider skip the values of 0 and 1 and thus, could not make the bases of the functions not to take the values of 0 and 1. Teacher's lack of technological knowledge results in a content error made while teaching the subject. Thus, the materials which were developed for the exponential and logarithmic function and which include the relevant error were evaluated as low-level materials in terms of technological content knowledge.

3.3. Technological pedagogical content knowledge errors in the materials

The evaluation of materials in terms of TPACK involves determining whether the content in the material has been presented with the appropriate technology and pedagogy. In a material that involves an error in this domain, the interaction of the errors made in technological and pedagogical knowledge domains leads to an error in the presentation of the content, as well.

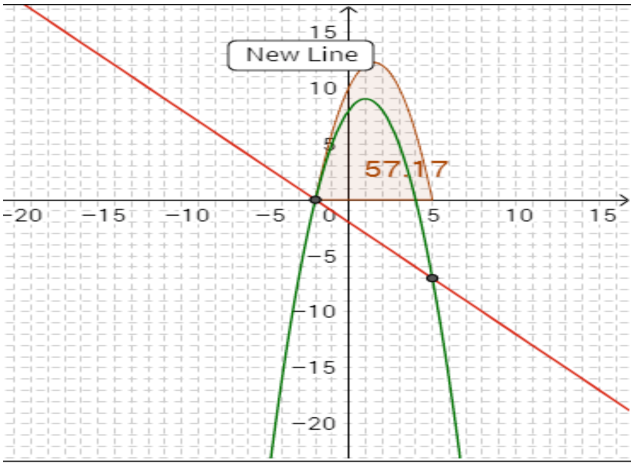

Figure 3. A sample error for technological pedagogical content knowledge

The material in Figure 3 involves calculating the area between two curves using GeoGebra. It is seen that technology was not used properly in the material and thus, the area between two curves could not be drawn correctly. This shows that the error stemmed from teacher's lack of TK. Furthermore, the algebraic expressions of the functions represented by curves were not included in the material, which indicates that an error was made in the material due to the lack of teacher's PK. When the errors made in technological and pedagogical knowledge domains are in interaction, the area between the two lines in the material cannot be calculated correctly. This means that a CK error was made in the material while teaching the subject. All these point to the fact that the material is at low level in terms of TPACK.

4. Discussion and Conclusion

In this study, the course materials developed by mathematics teachers using GeoGebra were evaluated within the framework of TPACK model. According to TPACK, evaluations of performance are conducted through the direct examination of teachers' performance in complex and authentic tasks (Rosenberg, Greenhalgh & Koehler, 2015). In this study, the materials developed by teachers to use in their own lessons were evaluated.

It was seen that in the majority of the materials, the teachers did not use the basic functions of GeoGebra and that the materials were merely developed to represent mathematical expression visually. The fact that the highest number of materials at low-level category is in the TPK domain indicates that the teachers in this study had more deficiencies in terms of technological pedagogy knowledge compared to the other knowledge domains. This situation has been supported by the fact that the highest number of materials are at low level and also, the lowest number of materials are at high level in this domain.

It was seen that the highest number of materials at high level was found in the TCK domain. Thus, it can be said that the majority of the materials are satisfactory in terms of TCK. On the other hand, it was seen that TCK domain is the second after the TPK domain in terms of involving the highest number of materials at low level, which indicates that a significant number of teachers need support in terms of TCK.

A large portion of the materials were found to be satisfactory at moderate level in terms of TPACK; however, this domain, together with the TPK domain, has the lowest number of materials at high level, which is a striking finding. This situation also indicates that the teachers in the study could not exactly meet the requirements of the TPACK domain. This finding coincides with the findings of the previous studies which revealed that teachers have deficiencies with respect to TPACK while designing teaching–learning environments in their classes (Gao et al., 2009; Koh, 2013; Lim & Chai, 2008). The studies which examined the classroom practices of teachers empirically revealed that teachers generally lack the TPACK, which hinders the design of meaningful learning with ICT (Gao et al., 2009; Koh, 2013; Lim & Chai 2008).

The errors in the materials developed by the teachers in the study were evaluated in detail with respect to the TCK, TPK and TPACK domains. The errors made in the TPK domain were that the equations of the curves whose graph was drawn were not given clearly; the algebraic window was left open in a way to confuse the student; and the sliders that should be placed on the coordinate plane in the material were placed in the algebraic window. It is remarkable that such errors related to the TPK domain were made frequently in the materials. The errors with respect to TCK in the materials are that the base of the exponential and logarithm functions can take the values of 0 and 1; the symbol for 90° cannot be fixed at the relevant angle in height construction; and the points that should be fixed in two- and three- dimensional shapes are left in a moving state. Although this problem is considered as a technological error, it was examined within TCK domain because of the mathematical conceptual errors it will cause. The errors made within the scope of TPACK, on the other hand, emerge as not being able to calculate the relevant area between two curves due to misrepresentation, and not being able to present the information that the graphs of inverse functions are symmetrical according to the $y = x$ line because the graphs of functions cannot be drawn symmetrically. When the errors are examined in detail, it is seen that the underlying reason behind these errors is that teachers are not competent in using GeoGebra software.

Another striking finding during the material evaluation process was that the materials prepared by the teachers did not have any instructions. Considering the fact that teachers developed the materials for their own classroom practice and they may have planned to give oral instructions during the activity, this aspect was not included in the evaluation in the current study. However, since teachers present the materials they developed in GeoGebra open course materials platform for other users, lack of instructions is considered to be a significant problem. In addition, having instructions are important to enable students revise the information presented in class; that is, instructions are important for the reusability of the material. In this respect, in teacher training sessions, the importance of adding instructions to the materials during the online material development process should be emphasised.

Although they were not the focus of the study and thus, were not given in the findings section, the subjects on which teachers prepared materials were exponential and logarithm functions at 38%, auxiliary elements of triangle at 29%, Pythagoras theorem at 14%, height construction and area calculation for parallelogram at 9%, 3D shapes at 5%, and the graphs of quadratic functions at 5%. The teachers were asked to develop materials considering the needs of students. The choices of the teachers revealed that teachers needed technology support mostly in the teaching process of exponential function, logarithm function and the auxiliary elements of triangle. It is suggested that the needs be revealed through more detailed studies and materials on specific content be developed and presented to teachers.

When teachers adopt constructivist teaching practices, they may encounter pedagogical conflicts, which TPACK assessment rubrics can address (Windschitl, 2002). In this study, the rubric developed by Harris et al. (2010) was used with the same purpose. While this rubric was used only with preservice teachers and lesson plans in the previous studies (Harris et al., 2010; Kereluik, Casperson & Akcaoglu, 2010; Rosenberg et al., 2015), it was used to evaluate the course materials of the teachers in the current study. Thus, it is believed that there is no problem in terms of validity and reliability. On the other hand, the reason behind evaluating course materials in this study instead of the lesson plans prepared by teachers needs to be explained. In fact, in addition to asking teachers to develop materials within the scope of the online course, the teachers were also asked to prepare a lesson plan for the learning–teaching process they designed. However, it was seen that the lesson plans prepared by the teachers were very similar and superficial. As Rosenberg et al. (2015) highlighted, this rubric can only be used when the lesson plans are prepared in detailed manner. Thus, lesson plans were not analysed during the data analysis process within the scope of the study. It is suggested that in the future, when teachers are asked to prepare lesson plans in online courses for teacher training, they should be warned about preparing more detailed lesson plans.

This study can be made more comprehensive by using different data collection tools like teacher interviews and classroom observations during the process of implementing the lesson plans and course materials teachers developed themselves. Further validation of the rubric is necessary. This could be done through more lesson plans and materials developed by both pre-service and in-service teachers and by varying the subject content. Furthermore, action research studies can be conducted with in-service teachers who use the rubric to support the ICT lesson planning process. This can help us to understand whether the rubric can be used in school settings.

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