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► To cite this version:

Melissa Meier, Hélia Oliveira. Using the TPACK model for the evaluation of tasks that integrate technological support to the learning of Mathematics. Twelfth Congress of the European Society for Research in Mathematics Education (CERME12), Feb 2022, Bozen-Bolzano, Italy. hal-04041728

HAL Id: hal-04041728

<https://hal.science/hal-04041728>

Submitted on 22 Mar 2023

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Using the TPACK model for the evaluation of tasks that integrate technological support to the learning of Mathematics

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The present study's main goal is to analyze the potential of the theoretical model of Development of TPACK in Teacher Education to understand what knowledge prospective mathematics teachers (PTs) have, and what they need to develop for the integration of technologies in planning digital materials for mathematics teaching, more specifically in the elaboration of tasks that integrate technological support to learning. The study was carried out within the didactic component of a master's degree in mathematics teaching. The data analysis focuses on the digital materials elaborated by the PTs and their individual reflections about the process. The results show both the pertinence and the limitation of the use of TPACK to evaluate these materials. Thus, there is a need to develop a specific model that considers the teaching action's particularity when times and spaces are flexible.

Keywords: Technology Uses in Education, TPACK, Mathematics Teacher Education, Instructional Material Evaluation, Mathematics Tasks.

Introduction

The emergence of digital technologies enables a continuous evolution of both mathematics and mathematics education. According to Balacheff and Kaput (1996), the main impact of digital technologies on mathematics education is in the epistemological and cognitive sphere because they contribute directly to the production of mathematical objects under new forms of realism. Thus, when students have access to digital resources that are suitable for the tasks they perform, such resources transform their way of thinking and doing mathematics.

Therefore, to create and implement learning environments that take advantage of emerging technology, teachers need to be holders of certain knowledge. They should know deeply not only the mathematics they teach, but also the technological tools available and their potential to explore mathematical ideas, as well as pedagogical aspects related to the teaching and learning of mathematics (Kim, 2016). The theoretical model Technological Pedagogical Content Knowledge (TPACK) (Misha & Koehler, 2006) offers a way to understand the types of knowledge a teacher needs in order to develop effective pedagogical practice in a learning environment equipped with technology.

As an expansion of TPACK, the TPACK Development Model in Teacher Education, proposed by Niess et al. (2009), is presented as a tool for evaluating teachers' prior knowledge, and indicating the knowledge that they need to construct. Adopting this perspective, this study aims to analyze the potential of Niess et al.'s model to understand prospective mathematics teachers' (PTs) existing knowledge for the integration of technologies when planning digital materials aimed at teaching mathematics, more specifically in the elaboration of tasks that integrate technology to learning. To address this goal, we have formulated the following research question: How can PTs' TPACK be

characterised when they plan and elaborate an online mathematics task that uses the features of the GeoGebra software?

Research has shown that PTs, in different contexts, face many difficulties in selecting rich tasks that integrate technology in an effective way for mathematics learning (Rocha & Palha, 2021). Thus it is an issue that needs further attention in initial teacher education research and practice. This research developed in the context of a course in *Didactics of Mathematics* taught in the first semester of a master's degree in mathematics teaching, at a university in Portugal in which we sought to identify and promote the PTs' knowledge on the use of digital technologies in the teaching of mathematics. As attention turned to dynamic geometry (DG) environments, GeoGebra was chosen for PTs to support the mathematical tasks due to its multiple applications within mathematics education.

Theoretical framework

The theoretical model TPACK (Mishra & Koehler, 2006), aims to propose a synthesis of the knowledge necessary for the integration of digital technologies for teaching and learning in the classroom (Chai et al., 2013). To guide and evaluate the development of this knowledge, Niess et al. (2009) propose the TPACK Development Model of the Mathematics Teacher, describing five levels of integration:

- (1) Recognizing, where teachers are able to use the technology and recognize the alignment of the technology with mathematics content yet do not integrate the technology in teaching and learning of mathematics.
- (2) Accepting, where teachers form a favorable or unfavorable attitude toward teaching and learning mathematics with an appropriate the technology.
- (3) Adapting, where teachers engage in activities that lead to a choice to adopt or reject teaching and learning mathematics with an appropriate technology.
- (4) Exploring, where teachers actively integrate teaching and learning of mathematics with an appropriate technology.
- (5) Advancing, where teachers evaluate the results of the decision to integrate teaching and learning mathematics with an appropriate technology. (Niess et al., 2009, p. 9)

Here it is important to clarify that, for Niess et al. (2009), the transition from one level to another is not necessarily sequential, because the progression of TPACK development is not linear. In fact, it is common that the emergence of a new technology requires rethinking its acceptance for the teaching and learning of mathematics, alongside reconsidering both content and methodologies.

In addition to the five levels described above, the Mathematics Teacher's TPACK Development Model is directed to four different themes, which are: curriculum and evaluation; learning; teaching; and access. In the search to clarify and systematise each of these themes, a set of descriptors have been provided (Niess et al., 2009): Theme 1 – *Curriculum and Assessment*, addresses the subject's treatment and the evaluation of students' understanding; Theme 2 – *Learning*, focuses on mathematics learning and conceptions regarding students' learning; Theme 3 – *Teaching*, the focuses on mathematics learning, instructional approaches, classroom environment and professional development; Theme 4 – *Access*, concerns students' usage, the teachers' approach to barriers to technological integration, as well as availability (thinking that technology results in an increase in the mathematics available, and in reaching a greater number and diversity of students). The descriptors'

evaluation, considering the teacher practice, makes it possible to determine previous knowledge presented by the teachers and indicates the necessary knowledge to be constructed by them in relation to each theme (Niess et al., 2009).

Context and methods

The study was carried out in the context of the aforementioned course using an interpretative and qualitative research approach (Cohen et al., 2007). The second author was the teacher responsible for the class, but both authors worked together in planning and teaching the sessions that concerned the use of technology. The participants are the cohort of PTs (N=15) who attended the course and who agreed to participate in the research. Most PTs had a strong mathematical preparation arising from their undergraduate studies, but only five had used GeoGebra before this course.

The work was directly linked to the transversal theme of the course, “Technology in the Teaching of Mathematics”, in which the PTs were required to create a mathematical task in Geogebra aimed at middle school or secondary students. This task should be a problem or a mathematical investigation. In addition, the group would present a solution proposal for the task. Finally, the material should be published on the GeoGebra software platform, in the GROUP tool. The GeoGebra GROUP tool was chosen because of its essential features, such as a space that allows for sharing resources, writing posts and comments, creating, editing, providing mathematical tasks and feedback.

The data for the study was collected from the work carried out in groups and by the participants’ individual reflections focused on the identified learning and the difficulties they faced when designing the mathematical task. Data analysis was based on technology integration steps related to the TPACK Development Model of the Mathematics Teacher (Niess et al., 2009), presented in the previous section. However, we have made an adaptation to the model as the present study centers on the evaluation of digital material elaborated by the PTs, that is to the teaching intentions expressed in the materials they propose, and do not present elements of effective classroom practice. The evaluation of the TPACK concerning digital material elaborated without targeting a specific content or class, leads to adaptations to the descriptors of the different Themes proposed by Niess et al. (2009), as it follows.

For the theme of *Learning*, it does not make sense to make an evaluation, as technology has already been selected. In our situation in which the PTs are required to develop tasks with technological support, the Advanced level is automatically reached, as the use of technology is an integral (and not an additional) part of the mathematics the students will learn. For the theme *Access*, it also does not make sense to evaluate the TPACK development as for the construction of a digital resource it is understood that the technology is available in the classroom for use by the teacher and the students. The evaluation on the theme *Curriculum and Assessment*, concerning the elaboration of tasks with technological support, it is generally pertinent, but in the case of this research study, as the content of the mathematical task was a free choice for the PTs, we can assume that they have already understood chosen content that they considered appropriate for technology integration. Regarding particularly the *Assessment* dimension, the task proposal did not presuppose this possibility.

Therefore, the focus of the TPACK analysis in this research is centered on the *Teaching* theme. Nevertheless, as technology is already an integral part of the task, we assumed that there are favorable

views towards the integration of technology in mathematics teaching, hence the professional development descriptor is not addressed. Thus, the descriptors of the theme *Teaching* we address in the study are related to *instructional approaches* and the *classroom environment*, adapted to virtual communication environment (the way PTs organize virtual communication).

The data analysis process began by evaluating the digital material produced by the four groups of PTs, using the descriptors above. After the material was collectively discussed in the class, the groups made some adjustments, and a new analysis was made by the research team. To complement this analysis, we read PTs' individual written reflections to look for their pedagogical intentions with the task and the integration of technology in that setting. The two researchers read all materials and discussed their analysis to reach a consensus view.

Findings

The PTs organized the group work, according to the following steps: (i) elaboration of a digital version of the requested task and uploading it to the GeoGebra platform through the "ACTIVITY" tool; (ii) creation of a digital version of the task's solution, using the "ACTIVITY" tool; (iii) complementing the didactic presentation of the material by creating a GROUP, also in the GeoGebra platform, where they inserted the files with the task and its resolution, in order to design its implementation with feedback possibility. We present a summary of these proposals (Figure 1) with the name and type (problem or investigation) that each group assigned to their respective task.

| GROUP | NAME OF MATHEMATICAL TASK | TASK TYPE |
|-------|-------------------------------|---------------|
| A | Riddle | Problem |
| B | Mathematical Problem | Problem |
| C | Relationships in the Triangle | Investigation |
| D | To the Discovery of the Angle | Investigation |

Figure 1: Summary of the tasks' proposals submitted by PTs

Regarding the development process of the PTs' TPACK, based on the material presented by the groups, we consider that, in general and, more specifically, in the theme *Teaching* with the *instructional* and *environmental descriptors*, the PTs completed the assignment at different levels.

Group A show characteristics of level 2, that is, the *Acceptance* of the integration of technology. The proposed task, named "Enigma" (Figure 2), has been classified as problem solving, and it replicates, with the use of technology, a task that can be solved using only paper and pencil. The model of Niess et al. (2009) specifically identifies this characteristic at the Acceptance level in the *Instructional Approaches* descriptor. When the teacher educators asked the PTs about the level of technology integration in the task, and to qualify and expand on their judgement, the group enhanced the proposed task, although it remained close to the first version. The group organized the instruction to the task, through predetermined steps, thus limiting an exploratory process. That is, they planned the construction of a geometric figure, including its dimensions and presented minimal information for its construction with GeoGebra, expecting a single and closed resolution as a solution to the problem

(Figure 3). In this new material, they evidenced a second characteristic of the level of *Acceptance*, but now in the *Environment descriptor*.

On the other hand, as we analysed this task, we noticed that the TPACK model does not allow an evaluation of the PTs' understanding *about* the differences in technology integration for the task's application and solution. In this respect, we observe that the levels of integration of technology in the task's presentation differ from a restricted use as motivational support (something that could easily be presented without technology) to the organization of a dynamic structure that serves as support for investigation, but that is also not indispensable for solving the task. The model does not establish a descriptor that contemplates the evaluation of this understanding.

| | |
|--|---|
| <p>Solve the following puzzle</p> <p>Have:</p> <p>5 building colors: blue, pink, yellow, green and orange;</p> <p>5 drinks: water, milk, tea, coffee and lemonade;</p> <p>5 animals: dogs, cats, rabbits, tigers and elephants;</p> <p>5 fruits: apple, anana, banana, melon and cherry;</p> <p>5 names of owners: Beatriz, Joana, Manuel, Francisco and José;</p> <p>5 building heights: 30m, 50m, 70m, 90m and 110m;</p> <p>Find out the height and color of the building, drink, animals and food corresponding to each owner.</p> | <p>Clues for puzzle resolution</p> <p>The first building belongs to Francisco;</p> <p>José doesn't drink tea;</p> <p>The person from the pink building eats bananas;</p> <p>The person in the blue building does not drink coffee;</p> <p>The person in the pink building does not drink tea;</p> <p>Those who eat ananais like tigers;</p> <p>...</p> |
|--|---|

Figure 2: Problem Solving Task presented by Group A

There is an empty land available for this condominium of buildings where it is intended to build a commercial area to meet the preferences of its owners.

We want to build:

- a Fruit shop
- a Liquor Store
- a Pet Store

Based on Enigma's solution and knowing that neighboring buildings are always at the same distance from each other, it helps us discover some information.

a) We want Fruit shop to be at the same distance as all buildings. This distance will be given by the difference in height between José ans Francisco's building. Where should this Fruit shop de built?

A

Figure 3: Complementing the Problem Resolution task presented by Group A

Group B show characteristics of level 3, which corresponds to the *Adaptation* category of the integration of technology in the descriptors aligned with the theme Teaching. In common with Group A, they proposed a task (Figure 4) that could be solved using only paper and pencil. However, Group B's task differs in relation to the *Instructional* descriptor due to their adaptation of the idea for technology integration. In group B's proposal, the solution with pencil and paper takes a lot of time and thus technology has the function of outsourcing work that could also be done by hand. In addition, the group proposed instructions that allow the exploration of different strategies for solving the problem, using technology, a characteristic indicated in the *Environment descriptor* of this level.

In the analysis of the material presented by group B, again, we notice that the model of Niess et al. (2009) does not include certain aspects for evaluating the integration of technology in the application

and resolution of a task. In the analysis of the material presented by this group, it is perceived that the model does not allow a level evaluation about how information is provided, in the way it integrates technology. In this respect, it is identified that the levels of presentation of information for the development of a task vary from widely detailed and explicit written instructions to the integration of applets in tasks that seek to contemplate different modes of resolution of the task.

Map of Mathematics
 Maria, Manoel e Miguel were gathered at the "SWING FOR FUN" amusement park when they realized it was time for dinner. Maria, as the oldest, accompanied her friends to their homes before returning to hers. Based on de map of Mathematics Country, trace the path taken by Maria, according to the information presented below. Use the available map, if you were not able to build the coutry map.

1. All friends live in different neighborhoods.
2. The Pitágoras neighborhood is not housing.
3. In the Mathematics County all streets are rectilinear.
4. The "SWING FOR FUN" amusement park is lotaed in the incenter of Pitágoras neighborhood.
5. Miguel's home is 5 miles from the Amusement Park and at the same distance from the University and the Hospital. The three friends have walked the shortest path.
6. To get to Manuel's home, they followed the road that connects Miguel's home to the Blue Flag. They turned at the intersection with perpendicular street ending in the lighthouse. The houses of the Miguel and Manuel are at the same distance from the intersection.
7. After leaving Manuel, Maria went to the Flag Blue. The distance between Manual and Maria's homes is the same between the Park and Miguel's home. Maria lives on the same street as Miguel.

Entrada...

Figure 4: Problem Solving Task Presented by Group B

The analysis of the work carried out by groups C and D allowed us to identify that these PTs present level 4 of the Exploration of the technology integration, as exemplified by Group D's task (Figure 5). According to the *Instructional* descriptor of this level, in the preparation of the task material's presentation, group D explored structured strategies to involve students in decision making using technology as a learning tool. It is possible to observe the extra material in addition to the task (Figure 6), which the group made available with the objective of supporting of the proposed investigation. This option also shows characteristics of the level of *Exploration* in the *Environment descriptor*, because, when providing support material, they assume its guiding role in students' exploration.

From the material presented by group D it is not possible to assess the level concerning how the material the PTs propose may organize an interaction with students. In other words, the level of integration of technology into established communication cannot be assessed. In this aspect, we notice that the integration of technology in the task for interaction and communication does not include, in any of these groups, a students' response with technological support. There is no evidence that PTs anticipate that the students can argue and communicate their reflections using technology.

To The Discovery of the Angle

Mr. Augusto, the bumbling engineer, was hired to develop a secret project. Accidentally lost one of the plan data. Part of the project is represented in the image below. He remembers that:

- [AC] is a diameter of the circumference of center B;
- [ED] is a string parallel to [AC];
- α has an amplitude of 80°

Can you help Mr. Augusto figure out the amplitude of the ABE angle without having to admit his clumsiness?

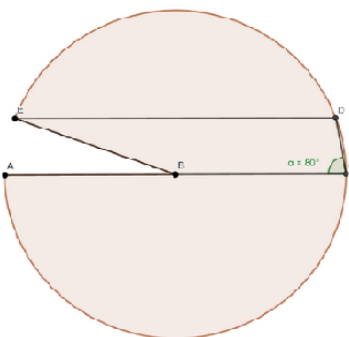


Figure 5: Research Task presented by Group D

Analyzes, Explores and Understands

First of all, develop the first ideas that come up when you view the image. It tries to realize the mathematical concepts relevant to resolution.

Explore the relationships between the different elements so that you can justify the solution found.

The following simulations may give you some clues to the resolution:




Figure 6: Example of support material used by Group D in the presentation of the task (Credit: Arthur Lee and Tim Brzezinski)

Based on the results achieved with this research, we can consider that, in general, the TPACK Development Model of the Mathematics Teacher (Niess et al., 2009) for the theme *Teaching* in the *Instructional* and *Environment* descriptor has the potential to evaluate technology integration levels in tasks with technological support to learning elaborated by PTs. However, our findings reveal that some aspects are not considered by the model and we conclude, therefore, that a complementation or expansion of the model is necessary to support its use as an evaluation tool.

Conclusion

Our study shows the pertinence and the limitations of the use of the TPACK Development Model of the Mathematics Teacher (Niess et al., 2009) in the evaluation of technologies' integration in the creation of digital materials, more specifically in tasks that include technological support for learning, aimed at mathematics teaching. The results show that the PTs have different knowledge about this theme, exhibiting three levels: *Acceptance*, *Adaptation* and *Exploration*. Thus, the model seems to allow us to discriminate between the different levels of PTs' knowledge when creating a digital task.

However, the adopted model does not meet to advance in the technology's integration, for example, regarding the didactic function of technology for the elaborated task, the role of technology in the information provided for the students' understanding and resolution of the task, and to the asynchronous communication to be implemented in the task's development.

It is important to highlight these necessary adaptations in the use of the model, since it was originally thought to describe in service teachers' knowledge (Oliveira et al., 2018) and in a face-to-face

teaching. However, it is essential to prepare teachers for the digital transformations of society and, specifically, as highlighted by Clark-Wilson et al. (2020), for scenarios where learning and teaching do not occupy the same space. This fact also demonstrates the need to expand this Model of Development TPACK of the mathematics teacher (Niess et al., 2009), as it does not provide elements of analysis of both distance education and design processes for digital materials focused on education.

This research enhances understanding in these contexts, and our future research will seek to contribute to the development of a specific model for the evaluation of the previous knowledge presented by mathematics teachers, as well as the necessary knowledge to be built by them about the elaboration and implementation of tasks with technological support to learning.

Acknowledgment

This paper received national funding from the FCT – Fundação para a Ciência e a Tecnologia, IP, within the scope of the UIDEF – Unidade de Investigação e Desenvolvimento em Educação e Formação – UIDB/04107/2020.

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