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Understanding the Technological and Pedagogical Content Knowledge (TPACK) of mathematics teachers as a possibility for reflection on the use of educational technology.

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ABSTRACT

Background: The broader access to technological resources, combined with pedagogical practices implementation, shows the need of continuing education of teachers on Digital Information and Communication Technologies (DICT). Recognizing the knowledge that professionals need in their work is a path that allows the evaluation and creation of training measures**. Objectives**: Considering the Pedagogical and Technological Content Knowledge (TPACK) as a reference, we sought to investigate the professional knowledge of mathematics teachers about digital technological resources and their possible incorporation in pedagogical practices**. Design**: A qualitative research was carried out. **Setting and Participants**: Mathematics teachers working in high school, technical and higher education who participated in a short-term training proposal. **Data collection and analysis**: The research was based on meetings with mathematics teachers, in which the use of resources was discussed and lesson plans were elaborated; they were, then, followed up in a real scenario. Specific instruments, lesson plans, audiovisual records, and interviews were analyzed by Textual Discursive Analysis (TDA), provided evidence about teachers' use of resources. **Results**: Different professional knowledge linked to TPACK were recognized at different levels and some factors such as professional experience and technological appropriation proved to be influential. **Conclusions**: In addition to the possibility of recognizing professional knowledge, it was noted that a specific character under the interpretation of TPACK recognizes such knowledge even in teachers with a low level of technology appropriation, which allowed reflections on the construct itself and its possible correlations with the Pedagogical Content Knowledge (PCK).

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Keywords: Technological Pedagogical Content Knowledge; Pedagogical Content Knowledge; Educational Technologies; Teacher training.

Compreensão sobre o Conhecimento Tecnológico e Pedagógico do Conteúdo (TPACK) de professores de matemática como possibilidade de reflexão sobre o uso da tecnologia educacionais.

RESUMO

Contexto: O acesso mais amplo aos recursos tecnológicos, aliado à implantação de práticas pedagógicas, mostra a necessidade de formação continuada dos professores em Tecnologias de Informação e Comunicação Digitais (TICD). Reconhecer os conhecimentos de que os profissionais necessitam para o seu trabalho é um caminho que permite a avaliação e a criação de medidas formativas. **Objetivos**: Tendo como referencial o Conhecimento Pedagógico e Tecnológico do Conteúdo (TPACK), buscou-se investigar o conhecimento profissional dos professores de matemática sobre os recursos tecnológicos digitais e sua possível incorporação nas práticas pedagógicas. **Design**: Foi realizada uma pesquisa qualitativa. **Ambiente e participantes**: Professores de matemática atuantes no ensino médio, técnico e superior que participaram de uma proposta de formação de curta duração. **Coleta e análise de dados**: A pesquisa baseou-se em reuniões com professores de matemática, nas quais foi discutido o uso de recursos e elaborados planos de aula; eles foram, então, acompanhados em um cenário real. Instrumentos específicos, planos de aula, registros audiovisuais e entrevistas foram analisados pela Análise Discursiva Textual (TDA), que forneceu evidências sobre o uso de recursos pelos professores. **Resultados**: Diferentes saberes profissionais vinculados ao TPACK foram reconhecidos em diferentes níveis e alguns fatores como experiência profissional e apropriação tecnológica se mostraram influentes. **Conclusões**: Além da possibilidade de reconhecimento de saberes profissionais, notou-se que um caráter específico sob a interpretação do TPACK reconhece tal saber mesmo em professores com baixo nível de apropriação da tecnologia, o que permitiu reflexões sobre o próprio construto e suas possíveis correlações com o Conhecimento Pedagógico do Conteúdo (PCK).

Palavras-chave: Conhecimento Tecnológico Pedagógico do Conteúdo; Conhecimento pedagógico do conteúdo; Tecnologias Educacionais; Treinamento de professor.

INTRODUCTION

Different authors consider that the introduction of technological resources has been occurring gradually in formal school environments, but pedagogical practices have not yet incorporated the use of such resources in their full potential (Valente, 1999, Kenski, 2012; Moran, 2015). They argue that education models that tend to underutilize digital technological resources

still prevail, disregarding the potential of a more active participation of students (Mattar, 2017).

We are for the use of digital information and communication technologies, understanding them as resources, tools, strategies, or as a structuring part of educational planning. Therefore, we understand the need of reflecting on the best way to incorporate them into educational planning, surpassing the mere use, which tends to dismantle the educational potential. Incorporating digital information and communication technologies presupposes the reflection on the pedagogical potential and the recognition of how DICT can be introduced in an environment that already has its own structure and culture—involving students, teachers, managers, and the community.

Thus, thinking about pedagogical practices that can insert DICT as a resource for learning implies knowledge of its characteristics. In education, most of the technological resources are already inserted in classrooms for some time. They are characterized by their specificity (a calculator is only for calculations) and stability (blackboard, mimeograph, overhead projector—they have not changed much over the years). These technologies were naturally incorporated in the educational practice, they became "common."

However, current digital technologies (computers, tablets, and cell phones) have no specificities; they can be used in many different ways—cell phones can photograph, film, calculate, play movies—and are unstable due to rapid evolution (Mishra & Koehler, 2013, p.13). When a technological resource has multiple purposes and can be used in different ways and contexts, educators must consider their advantages and disadvantages more carefully before using them during classes. All uses of digital technologies in education must be linked to the objectives of the educational proposal and this interconnection must be structured on the teaching plans of the educational actors.

In this sense, technologies should not create digital copies of pedagogical practices that were already developed and the process should not be an exchange, but an opportunity to explore a new problem or solution that would be impossible without technology, creating environments with new, more disruptive approaches[1].(Harris, Mishra, & Koehler, 2009).

[1]We adopted the term 'disruptive' in the sense of an education model that redraws methodologies, based on activities, challenges, problems, and games, in which students

Considering the existence and imminence of the use and implementation of DICT in educational environments, it is essential to promote studies on teacher training for the use of technologies. Some points that are worth investigating are aspects related to technological adequacy, uses in specific environments, and investigations about professional knowledge (Valente, 1999; Sampaio, 2013).

The investigation of the integration of DICT aimed at the educational process cannot be done based on a reductionist approach. This observation should expand beyond technological resources. The educational process is a complex system that involves multiple scales and facets. To understand this integration, in addition to the technological knowledge of teachers, it is also necessary to investigate knowledge about pedagogical practices, content, and the school context itself.

Considering these criteria, the main objective of this study was to investigate how the integration of pedagogical and technological knowledge of mathematics teachers occurs during classes with DICT, through the recognition of professional knowledge mobilized throughout the planning and execution of the teaching activity. The model developed by Mishra and Koehler (2006) of Pedagogical Technological Content Knowledge (TPACK) was adopted as a basis. For the investigation, it was necessary to understand what teachers know, how they use digital technological resources in their classes, and, especially, if the used digital technology is incorporated into professional practice during their performance.

Therefore, the specific objectives of this study were to recognize the professional knowledge of two mathematics teachers working at a federal educational institution; to investigate how teachers mobilize their knowledge during their professional practice with DICT; to analyze if and how this knowledge is integrated with the professional knowledge in pedagogical practice.

THEORETICAL FRAMEWORK

Discussions about necessary knowledge for teaching have valued the practice, signaling directions for the development of teacher training. Therefore, we reviewed the interpretations of Pedagogical Content Knowledge

learn at their own pace and need, as well as with others in groups and projects, with teachers' supervision (Moran, 2015).

(PCK), and of the theoretical proposal of Pedagogical Technological Content Knowledge (TPACK) in different studies that used these models in order to build elements for our analysis.

Some authors consider that professional knowledge for teaching can be seen as more specific components and, in some cases, as amalgam of several of these, being apprehended and developed during initial and continuing training (Shulman, 1986; Harris & Hofer, 2015; Mishra & Koehler, 2013).

According to these references, the study of professional knowledge is guided by the proposition of a knowledge base for the professional teacher. In Shulman's (1986) proposal for the referred base, there are seven categories or domains of knowledge; of which the Pedagogical Content Knowledge (PCK) stands out. For the author, it represents an integrative construct of different domains that the teacher uses to transform the content for teaching.

This knowledge is not just a repertoire of techniques that the teacher uses to teach, it is characterized by a way of thinking that is proper to the teacher: an ability to make the content understandable, considering the teaching purposes, the educational environment, and student diversity. As an intersection between diverse aspects of specific content and knowledge from the pedagogical area, it develops itself before, during, and after the action through reflexive processes (Shulman, 1986).

Based on Shulman's works, several authors proposed interpretations for the PCK, which culminated in numerous works with varied focuses. In 2012, a project called "the PCK Summit" brought together researchers with the purpose of discussing the existing models. More recently, after discussions to refine the concept behind the PCK, a current model called the "Refined Consensus Model" (2019) was proposed, represented in Figure 1.

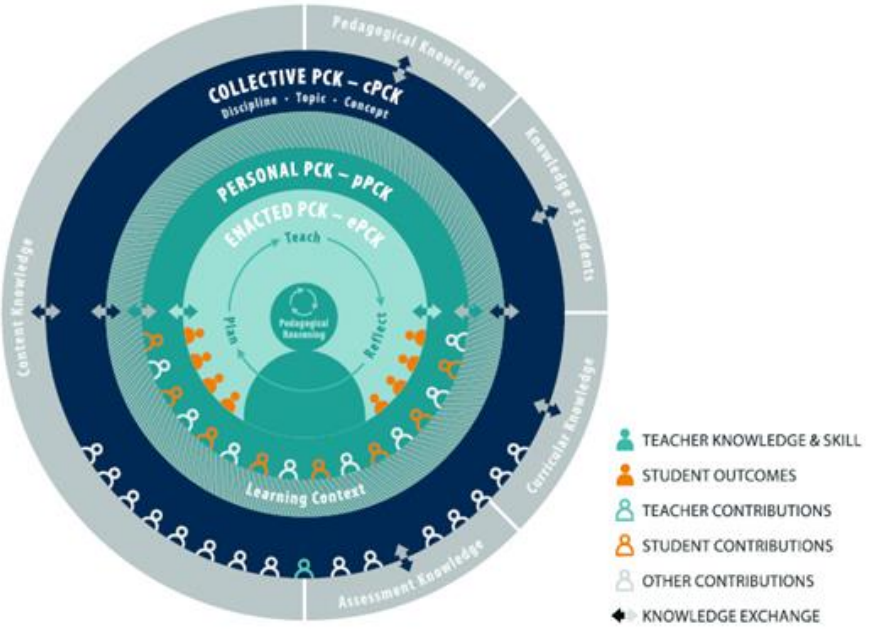
Although the summit researchers arrived at a detailed and highly complex PCK model, this proposal does not (explicitly) incorporate aspects related to the use of technological resources and, in the various interpretations of the PCK, we did not find direct reference on the use of DICT in the classroom.

Shulman (1986) himself did not discuss the use of technologies in his proposal for the PCK because, when he proposed it, in the late 1980s, issues involving technology in education were not in emphasis as they are today. However, if we consider that the use of examples or analogies and teaching strategies are important for PCK—to represent content in a understandable way for students—technologies can contribute to this role, since they offer a range

of representations, explanations, and demonstrations that can help make a subject more accessible.

Figure 1

Refined Consensus Model of Pedagogical Content Knowledge – RM from PCK (Carlson and Daehler, 2019, p. 83)



The PCK interpretation leads us to the understanding that technologies are already incorporated in more specific domains of knowledge, such as pedagogical knowledge and educational context knowledge, for example. However, within the scope of the investigation of professional knowledge focused on the use of DICT, new proposals recognize that the use of such resources requires a particular knowledge, which presupposes a new pedagogical approach and even a new look at the content.

From this perspective, the Technological and Pedagogical Content Knowledge (TPACK) proposal emerges. It considers technologies as a particular knowledge that integrates pedagogical components and content; it

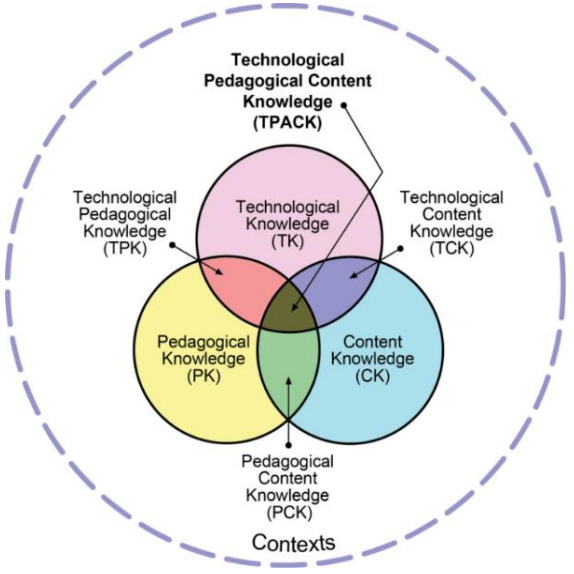
uses, in its origin, Shulman's (1986) design of the knowledge base, integrating the component of technological knowledge.

TPACK has been referenced by different authors who study teacher training focused on the use of DICT (Harris and Hoffer, 2015; Sampaio and Coutinho, 2013).

The TPACK model suggests that we must consider three different knowledge domains—Content, Pedagogy, and Technology—to better approach technology in teaching and learning processes. From the intersection of these circles, four other types of knowledge emerge: Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and TPACK (Figure 2).

Figure 2

Technological Pedagogical Content Knowledge model - TPACK model (Mishra and Koehler, 2006).



What defines this model is the articulation of technology, pedagogy, and content. More important than looking at each separate component, it is

looking at them in pairs, a similar movement to that made by Shulman (1986), who considered the relationship between content and pedagogy.

The external dotted circle, called context, signals that knowledge exists within specific teaching contexts. The actions of a teacher who works in a class with access to the internet and cell phones are different from those in a situation in which students have to go to a computer lab and share computers to develop an activity. The knowledge that the teacher has to mobilize is different in these two contexts and this alters the structure of lesson and activity planning.

Each knowledge displayed in the TPACK model can be described as:

- **Content Knowledge (CK)** – The knowledge of teachers about the subject they teach. This includes concepts, theories, ideas, organizational structures, and evidence.
- **Pedagogical Knowledge (PK)** – The knowledge about teaching and learning practices and processes. It is the understanding of how students learn, how to manage a classroom, how to plan a lesson, and how to assess students.
- **Technological Knowledge (TK)** – This knowledge is constantly evolving; it does not mean understanding a specific technology well, but rather having the ability to learn and adapt to new technologies that are yet to appear.
- **Pedagogical Content Knowledge (PCK)** – The knowledge that teachers use to transform the content for teaching.
- **Technological Content Knowledge (TCK)** – it is understood by the way technology and content simultaneously influence and restrict each other. The choice of technology may limit some representations of the content, in the same way that may allow the construction of newer and more varied representations of the chosen content.
- **Pedagogical Technological Knowledge (TPK)** – it is the understanding of how certain technologies can alter teaching and learning. It is to know the possibilities and restrictions of a variety of tools and to relate them to pedagogical strategies, with the ability to choose a tool based on its appropriation.
- **Pedagogical Technological Content Knowledge (TPACK)** – it is the basis to teach with technology. It requires an understanding

> of pedagogical techniques that use technologies in a constructive way, to strengthen previous knowledge and develop new knowledge.

As previously discussed, there are two ways of visualizing the use of technological resources. The TPACK perspective situates technologies beyond a teaching tool/resource, understanding them as a particular knowledge of the teacher that needs to be integrated into other domains. It is its own construction and not a product derived from other knowledge. In PCK models, technology is incorporated in different categories of knowledge.

Cox and Graham (2009) reinforce that, as specific digital tools and resources become more present in schools, technologies will be included in the PCK. However, they also predict that "there will always be a need for TPACK as long as there are new emerging technologies that have not yet become a transparent, ubiquitous part of the teaching profession's repertoire of tools" (p. 64). According to the authors, from the moment that a digital technology is integrated into the professional teaching practice and becomes transparent, knowledge about this tool can be included as a resource within PCK. Therefore, TPACK allows us to look in the direction of technology appropriation for educational uses already in the moment of professional training for DICT use.

In the literature, some research proposals consider the PCK with the use of technologies as instructional strategies/resources (Oliveira, Henriques and Baptista, 2019; Clebsch and Alves Filho, 2018) and, therefore, they do not use the TPACK model; other research proposals adopt its perspective for professional knowledge interpretation (Sampaio, 2016; Aieta and Cabral and Segadas, 2016).

Regarding investigation procedures, data collection, and processing, different studies investigate how to look at the professional knowledge of teachers from the TPACK perspective in classes using DICT. The work developed by Candela (2017) adapted the Content Representation (CoRe) instrument to the theoretical framework of TPACK. The CoRe is a data-collection instrument composed of eight questions related to the PCK knowledge base: knowledge of content, students, teaching strategy, and evaluation (Loughran, Berry and Mulhall, 2006). For the author, as digital technologies are an instrument of content representation and effective classroom management, it is pertinent to adapt the epistemological structure of the CoRe to the TPACK theoretical framework, so that the instrument continues to be used in education programs, in which designing learning environments is important for teachers' professional development.

Harris and Hofer (2015) present a lesson planning process with different types of learning activities (LAT – *Learning Activity Types*). The development of LAT is based on teaching planning. It involves a sequence of actions of selection and reflection on the teaching-learning process, using technological resources and TPACK development.

It was observed that surveys mostly use interviews and questionnaires as data collection methods (Oliveira, Henriques and Baptista, 2019; Sampaio, 2016; Alcântara, Dullius and Carreira, 2016; Cyrino and Baldini, 2017). In order to approach the attitudinal knowledge of teachers, other authors describe studies with the observation of teachers' performance in real contexts, thus recognizing declarative and also procedural knowledge (Gess-Newsome, 2003; Oliveira and Mozzer, 2017; Lopez, 2019, Patriarch, Costa e Silva, 2019)

In view of the diversity of produced studies and the questions that arise about the references, in this study, we adopted the TPACK as a possibility of looking at how technologies are integrated with the pedagogical practices of teachers, since we do not know, a priori, the degree of technology appropriation of teachers.

Based on the review described so far, it is possible to observe different paths that can be chosen when considering the TPACK framework. We tried to clarify these different possibilities and, based on our investigation, we aimed to consider which path or paths fit our specific context.

Through the performed review, we sought to converge methods that could complement each other to contribute to the research field in question. Data collection procedures, based on TPACK knowledge, allowed us to study the facts in their natural environment, interpreting or seeking to understand events, which supported the goal of investigating teachers' relationship with DICT—a fundamental, but not unique aspect of the research.

METHODOLOGY

For the proposed investigation, a qualitative research was chosen: a case study with a non-participant observation. Data were collected in a real environment that involved the practices of the mathematics teachers involved as subjects of the investigation (Bogdan; Biiklen, 1994; Thiollent, 2008).

The research was carried out at a Federal Educational Institution (IFE – *Insituiçao Federal de Ensino*) in the state of São Paulo, with high school

teachers and college professors (BA and Licentiate)[2]. The adhesion was voluntary after the researcher invited them to participate in meetings with subsequent observation of their classes, in which they used digital technological resources. Since we intended teachers to prepare a class using DICT, the proposal did not limit the use of a particular technological resource, nor a pedagogical practice or specific content.

Research steps and data-collection instruments

The meetings, under the guidance and organization of the researcher, initially occurred in person with all participants, to share experiences with the use of DICT and to elaborate lesson plans.

Using the concepts of flipped classroom and hybrid teaching, we met in 3 (three) face-to-face meetings of around two hours. We previously shared articles and links as reading suggestions, to make the best out of the face-to-face meetings and deepen the discussions. Between one meeting and another, the teachers had a 15-day-period to browse through the material.

In the first meeting, the addressed topic was the interaction of technology in teaching and their levels of technology appropriation. The teachers discussed the integration of the resources they used and their difficulties in the classroom.

In the second meeting, teachers discussed and evaluated some case studies. Considering active learning, they worked on themes related to virtual platforms, educational resources, and education experiences. One of the main focuses of this meeting was working with teaching strategies.

In the third meeting, teachers shared and discussed their plans. Each participant presented the class plan, the objective of the content, and the technological resource.

After the meetings, we accompanied each teacher in the execution of the planned classes. The classes occurred in a real setting; they were scheduled in conventional rooms, computer labs, or mathematics teaching labs, depending

[2] The project of the present study was submitted and approved by the Research Ethics Committee of UNICAMP under the CAAE number 87462318.8.0000.8142.

on the teacher. All classes were practical and, during observation, we made some notes in addition to the audiovisual record.

After the classes, semi-structured interviews were conducted, based on the observations of the entire process, focusing on how the teachers developed their knowledge about that DITC, what was the relationship of the resource with the content, and what specific teaching strategy was used in class.

DATA-COLLECTION INSTRUMENTS

Data collection was performed using the following instruments: Lesson plan, CoRe, SCoRe (Strategy Content Representation), class observation, and interviews.

Content Representation – CoRe

CoRe is a data-collection instrument composed of eight questions related to the PCK knowledge base (Figure 1). It was used in conjunction with the lesson plan to identify the teachers' professional knowledge for DICT use, and the relationship of the resources with the content and pedagogical practices. The instrument allowed us to access teachers' knowledge about a specific content and to analyze their knowledge base comprehension.

Figure 1

Content Representation – CoRe Instrument (Loughran, Mulhall and Berry, 2004, Girotto Junior Translation, 2011.)

	Specific content		
	Topics / Central Concepts related to content		
	Idea 1	Idea 2	Idea 3
1. What do you want students to learn from this idea? (CK)			
2. Why is it important for students to learn this idea? (CK)			
3. What else do you know about this idea? (PK, CK, PCK)			

4. What are the difficulties and limitations associated with teaching this idea? (PK, CK, PCK)			
5. What knowledge about students' thinking has an influence on your way of teaching this idea? (PK, CK, PCK)			
6. What other factors influence the teaching of this idea? (PK, PCK, TPK)			
7. What procedures and/or strategies do you use to make students commit to this idea? (PK, PCK, TPK)			
8. What specific ways do you use to assess students' understanding or confusion about this idea? (PK, PCK, TPK)			

Strategy Content Representation – SCoRe

Like CoRe, SCoRe has questions that promote the reflection on important aspects of the strategy used to teach a certain content. Each strategy uses the instrument to show the understanding of the strategy, stimulate reflection and possible expansion of PCK. It was used with the lesson plan to investigate teachers' professional knowledge about the adopted teaching strategy and its relationship with the use of DICT.

SCoRe was used to recognize knowledge about teaching strategies (PK) and their relationship with content (PCK). If the strategy involves the use of technologies, we can also obtain TK and TPK information. It originated from an adaptation of the CoRe by Girotto Jr, De Paula and Matazo (2019) to recognize information about teaching strategy of a specific content; it aims to recognize possible knowledge related to strategy: its application, its potential, and its limitations (Figure 2).

Figure 2.
Strategic Content Representation – SCoRe Instrument (Girotto Junior, De Paula and Matazo, 2019)

Teaching strategies (TS) used for the content:	TS1	TS2	TS3
1. What, in addition to the specific content, do you want students to learn from this strategy? (TK, PK, PCK, TPK)			

2. Why is this strategy important for student learning/assessment? (TK, PK, PCK, TPK)			
3. What else do you know about this strategy? (TK, PK, TPK)			
4. What are the difficulties and limitations associated with this strategy? (TK, PK, TPK)			
5. What prior knowledge of students influences the use of this strategy? (TK, PK, TPK)			
6. What other factors influence teaching with this strategy? (TK, PK, PCK, TPK)			
7. What procedures do you employ (or are necessary) to use this strategy? (TK, PK, TPK)			
8. What specific ways do you use to assess the effectiveness of this strategy? (TK, PK, TPK)			

Lesson Plan

The lesson plan, along with CoRe and SCoRe, aimed to recognize which strategies would be used to teach specific content and which technologies would be used during the observed class. The description provided by the teachers in the plan, complemented by the CoRe and SCoRe responses, may reveal evidence of their PCK and TPACK.

Class Observation and Recording

By individually accompanying each teacher in the class described in the plan, we sought to recognize the mobilization of professional knowledge. This non-participant observation took place in a real setting, with audiovisual record and transcription to investigate the teachers' relationship with the content, pedagogical practices, and the use of DICT in the classroom.

Final Interview

The semi-structured interviews happened after class observation and were aimed to recognize possible actions related to how the teachers developed and mobilized their knowledge, focusing on the process of stimulated reflection as well as on questions about what had been planned and what was performed in the practical action of the class. In this process, we started with questions

common to all participants and, during the interviews, other questions were made, according to each teacher.

DATA ANALYSIS

Data analysis and triangulation led to an understanding of how much content and pedagogical practice are related to the used DICT.

Data were analyzed individually and the answers were grouped and categorized through the Discursive Textual Analysis (DTA). Through DTA, we can analyze data with previously established categories, which were associated with data from the lesson plan texts, CoRe and SCoRe, as well as from the transcription of class observations and interviews. All textual material from each teacher was grouped into a single individual analysis. The next steps were the fragmentation of data and the creation of different units of meaning, linked to the initial categories.

The DTA consists of an analysis methodology that seeks results in the phenomenological scope, but it is located among the proposals for discourse and content analysis. Although some of the pre-established and emerging categories are related to content, we considered that DTA was more appropriate than content analysis since we sought to understand the content integration process through the practical and reflexive process of the research subjects.

Identifying the contents and drawing relationships with citations could simplify the analysis and not allow the observation of how knowledge integration occurs when reflecting upon it and in practice.

Therefore, we worked with more general characteristics first, to encompass the largest possible set of data, to then compact and approximate them. To reach the final categories, they were reorganized according to the research objective, which enabled the production of a metatext.

Initially we worked with 15 categories that emerged due to the reference analyses, that is, they were linked to the knowledge base of Shulman (1986), the TPACK model, and technology appropriation. To recognize the largest amount of information in the data, we proceeded with the fragmentation of the materials to recognize units of analysis that were linked to these categories.

Through the unitarization and grouping of units of meaning, some of the initial categories were grouped and rewritten, generating 10 intermediate

categories, which, after analysis and group discussion, resulted in six final categories that we believed represented the obtained data.

For each final category, we sought to clarify the meanings and interpretations, as well as to weave the relationship of the categories with the associated domains of knowledge of the TPACK model:

C1 – Specific content representations: the purpose is to teach the selected content. We tried to access the content in an indirect way, through units of meanings that included speeches or actions that demonstrated information about the content that was associated with the teaching purpose.

C2 – Use of specific strategies: knowledge of the selected pedagogical practice, be it a strategy or a resource used in the classroom. We also tried to access the knowledge of the practice in an indirect way, through units of meanings that included lines or actions that demonstrated information about the selected strategy for the observed class.

C3 – Aspects related to other knowledge: knowledge mobilized in the classroom that collaborates with the integration of technological resources.

C4 – Aspects related to Digital Technological Knowledge: general knowledge about DICT, both about the technology used in the observed class and other technologies.

C5 – Aspects related to Technological Knowledge of Specific Content: knowledge about selected DICT that is related to content.

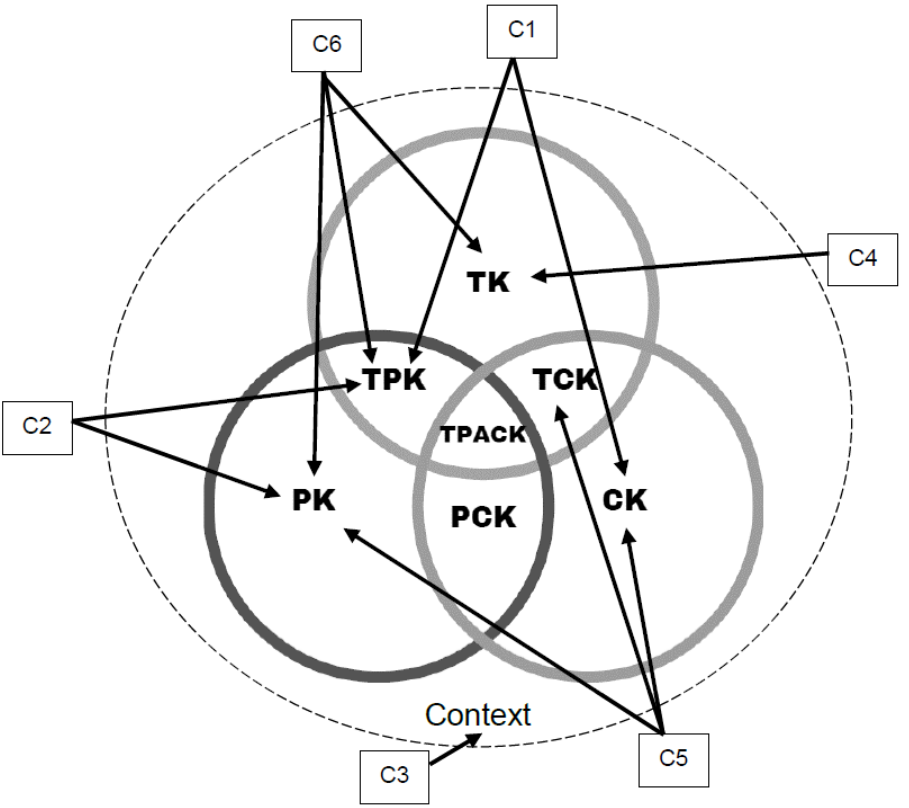
C6 – Aspects related to Specific Pedagogical Technological Knowledge: knowledge about the selected DICT that is related to pedagogical practices.

Figure 3 illustrates the TPACK model by Mishra and Koehler (2006), in which we associated the final constructed categories.

With this set of categories, we elaborated the analysis proposal. Now, we discuss, in detail, each of teachers who participated in the research.

Figure 3

Knowledge associated with Emerging Categories



RESULTS AND DISCUSSION

Initially, six teachers agreed to participate of the process and, in the end, two did not complete it, alleging lack of time. In this article, for dimensioning reasons, we approached the results of two teachers who clearly demonstrated the analyzed diversity and the different obtained results. We adopted the acronyms P1 and P2 to refer to the teachers involved in the research.

Data analysis of teacher 1 (P1)

Professor P1 has a degree in Mathematics and Physics, a Ph.D. in Energy Systems Planning, and more than ten years of teaching experience; the teacher has been working at the IFE for three years with mathematics subjects in higher education courses and in technical high school courses.

Class Description

The theme chosen by P1 for the planned and observed classes was arithmetic progression (PA) and geometric progression (PG). The three mathematics classes observed were given to the 2nd year of technical high school (mechanic technician course). In a conventional classroom, students brought their own notebooks to develop a group activity. Using spreadsheet software (Excel), each group created a table and graph for a presented problem to find a function that represented the created values. The chosen DICT for this class was the Excel software , used in the PA and PG content with a pedagogical practice of solving problems in groups.

For each group, a problem was presented and students should understand the situation to create the values and compose the table. The teacher stimulated students' participation by orienting the groups in a way that the students related the created table and graph to the content of previous classes.

Through Discursive Textual Analysis, we gathered the information from the lesson plan (P), CoRe (C), SCoRe (S), class observation (O), and interview (E) for P1. In Table 1, we organized some of the units of meaning (column 2) separated by categories (column 1).

Table 1

Units of Meaning associated with the categories for P1, obtained by analyzing the different materials

Categories	Units of Meaning
C1 – Specific content	P2U2: "Observe how the sequence of numbers is constituted (if they increase, decrease, and how that happens)." (C) P2U3: "By developing this type of observation, it is expected that students will be able to set standards and create expectations of results in different contexts." (C)

	P2U10: “That graphs can take on different formats, depending on the analyzed sequence. These formats can be approximated for functions of 1st and 2nd degrees, as well as for exponential and logarithmic functions.”(C)
C2 – Specific strategy	P2U11: “[...]I want you to try to create a table of the situation that I am going to assign to the groups. That is why we will use Excel: to make it easier to organize the ideas. From this table, you will build the graph that you think best defines the situation, making it easier to visualize the data that you are working on. And then, from the graph, try to find the function that describes it.” (O) P2U22: “I present different strategies for observing and analyzing the graph, trying to encourage them to see results and interpretations that they have not seen before.” (C)
C3 – Other Knowledge	P2U25: “Today, the interpretation of graphs and other types of schemes is increasingly out of date. As this type of information is vital in all areas of our lives, students are expected to be able to work with this way of presenting and interpreting information.” (C) P2U26: “[...] I understand that the more I know about the students’ thoughts, the more easily they will understand my explanation.” (C) P2U27: “[...] I have to know the class profile. Some groups are more apathetic, or more technological, or more artistic, so I try to figure out what method will be the most pleasing there and more adequate to my content.” (E)
C4 – Digital Technological Knowledge	P2U29: “So, Excel is like this for me: the tool that I ended up developing a little better because of the contact I had with it since I was practically a child. And then in post-graduation too, the charts and tables that I always made or used were in Excel. And, during college, I ended up learning to work with formulas [...]” (E) P2U31: “I often use Geogebra to show students [...] besides, there are games [...]” (E)
C5 – Technological knowledge of specific content	P2U37: “For me, it is important because it helps visualize the same content differently. [...]In addition, the analyzes are much easier to observe with a graph.” (E) P2U38: [...] “then, I saw that Excel also worked; you could insert the equation of the graph, of the straight line, in short, whatever function you had. Then I started to learn how to use it, and as you learn, you see the almost infinite possibilities that you have in the program.” (E)

C6 – Specific pedagogical technological knowledge	P2U39: "it helps students develop greater skills in other tools that can be used for their learning or in their future work." (S) P2U41: "it facilitates the quick visualization of results. That way, they can create more hypotheses and quickly test them." (S) P2U42: "The chart should be made first, then you have an option inside Excel that allows to analyze the format of your chart and, then, it gives the trend line, which is already the function. So, you insert situation first—the numbers—then we build the graph and it's easy for us to see the trend." (O)

Through the units of meaning, which some are presented in Table 1, we can see that the teacher demonstrates the purpose of learning the mathematical content. Thus, the mobilization of the CK is noted. Also, in relation to group work, data demonstrated that the teacher knows the potential of this teaching approach, allowing the recognition of the mobilization of knowledge associated with the PK.

What we can observe is that P1 considers the particularities of each class and student to develop a more appropriate lesson plan for each content (C3). The teacher's knowledge goes beyond pedagogical and content practices, recognizing the teaching context—represented by the dotted circle in the TPACK model.

The data reveal that the teacher presents the knowledge of other technological resources. Regarding Excel, P1 mentions that he has been using it for a long period of time, both for personal and pedagogical use. A knowledge that seems to add to the teacher's pedagogical and content knowledge, which are already part of the professional teaching knowledge.

In this way, the teacher demonstrates to know the possibilities of relating DITC with the chosen pedagogical strategy. Even though it is a technology that was not specifically developed for classroom use, P1 relies on the resource to advance students' learning and understanding.

A general look at the analyzed categories allows us to infer that the class observations and the information described in the planning are complementary. For all categories, we verified units that illustrate the mobilization of the teacher's knowledge in relation to the content (C1), strategies (C2), and context (C3), which involves the educational environment and how he considers it for his practice. P1 seems to use knowledge of content and strategies to encourage students to visualize new results, concerned with

developing a lesson plan that considers the individuality of the student or the class.

In the interview, information about the teacher's technological knowledge, in general, can be accessed. The teacher pointed out, at different moments, to move towards a citizen profile with technology appropriation, along the lines of what Valente (1999) and Sampaio (2013) described, in excerpts like the following:

> *P2U30: "I used it a lot, for example, in the first private school where I taught, in 2012, in which they asked me to make a project with them about financial education. [...]"*
>
> *P2U34: "I also usually recommend a lot of videos for them to watch. There are some things from Khan Academy, which I sometimes ask them to do." (E)*
>
> *P2U35: "One of the things I miss, which I had at Sesi and not here, is NXT. I had it there. Lego, small robots. [...] I remember, until today, that we made one and the result that the robot drew was a sine wave. Then, I discussed with them why that oscillation happened, what that was, period and everything, you know, we discussed about it. That would be an example of an experiment that I would use to teach trigonometry to them, if I could do it here." (E)*
>
> *P2U36: "Actually, what I end up seeing is what suits that content best, because some software are geared more towards Geometry, more towards the Algebraic part—graphics—which makes it easier for students to visualize, so I'm always looking for that." (E)*

We emphasize this information because, in the case of P1, we are dealing with a professional who not only knows other resources, but also demonstrates being able to select different resources for teaching in different contexts, adapting the practice to the educational scenario. This characteristic provides us with evidence of the integration of technologies to content and pedagogical knowledge.

P1 manages to mobilize the use of the resource to approach new knowledge due to its use with students being a proposal that is naturally inserted as a teaching resource.

This teacher mobilizes various knowledge to teach with DICT. P1 knows resources and is, thus, able to choose which one suits a specific context best and, furthermore, the teacher's technological knowledge seems to be incorporated into the pedagogical and content knowledge.

Since different knowledge was mobilized during the monitoring of P1 activities, we recognized them as related, since we noticed (not only during the lesson) the use of knowledge associated with the objectives of the class; the assessment purposes; and the consideration of students' knowledge and the context to select the best strategy and resource, or the resource P1 deemed most appropriate according to the educational purposes. This comprises an integration of knowledge proposed by the TPACK model.

Data analysis of teacher 2 (P2)

With a degree in mathematics, a master's, and a doctorate in mathematics education, this professor has fifteen years of experience teaching and has worked at the IFSP with mathematics subjects in the Mathematics Degree course for nine years.

The two classes were observed on the topic of sequence convergence; they were planned for a class in the eighth semester of the Mathematics Licentiate Degree Course. In the mathematics teaching laboratory (MTL), students were instructed to work in a group, in an exploration and discussion task about the content, using the computer and the Geogebra program as support.

Through Discursive Textual Analysis, we gathered the information from the lesson plan (P), CoRe (C), SCoRe (S), class observation (O), and interview (E) for P2. In Table 2, we organized some of the units of meaning (column 2) separated by categories (column 1).

Table 2

Units of Meaning associated with the categories for P2, obtained by analyzing the different materials

Categories	Units of Meaning
C1 – Specific content	P3U1: "The concept of sequence and series convergence and their properties." (P)

	P3U2: "The idea of sequence convergence is a fundamental theme of Mathematical Analysis that constitute the mathematical knowledge of the future teacher." (P) P3U4: "It is often not clear to them the relationship between the index of the sequence and the distance of the terms, from that index, to the limit of the sequence, when it exists." (C)
C2 – Specific strategy	P3U6: "Use of exploration tasks to address content, group work, and discussion." (C) P3U7: "Because it allows students to build their own knowledge and to establish connections with other content." (S) P3U10: "The use of questions to stimulate thinking about the content and its connections with other topics." (S)
C3 – Other Knowledge	P3U11: "[...] they don't remember the definition, or the definition didn't make sense. From the moment we had these discussions—and I believe that the software helped them to see that relationship: as you progress in the sequence, you get closer and closer to the supposed limit—I realized that the definition was clearer. [...]" (E) P3U12: "The knowledge about the content, which they already bring from the Differential and Integral Calculus semesters they attended." (S)
C4 – Digital Technological Knowledge	P3U17: "Well, I use a projector when I work on something expositive, then, I use PowerPoint or Latex to design something and that's about it. The use I make from technologies is very limited. [...]" (E) P3U18: "I applied Geogebra, whenever possible, to see if maybe they could understand the content better. But it was in that expositive way, the practice was nothing different [...]." (E) P3U14: "As soon as I started here at the IF, the licentiate degree course began, I gained interest [in DICT] precisely to be able to do things with students. [...] Thais (teacher with fictitious name) already used Geogebra with a certain proficiency and then I thought 'I need to learn too,' right? And then I started to use it. I started to use it, but then I stopped. I didn't use Geogebra again for a while. I would say for a few years, even. I think that I came back to it this year because of the stimulus of the research, so I started to work with it again." (E)
C5 – Technological knowledge of specific content	P3U19: "The use of DICT as a means to promote mathematical thinking." (S) P3U20: "The idea was that we would build a definition based on the idea that they were realizing through the software." (E) P3U21: "I always thought about the sequence in a unidimensional way, in the points of the sequence, for example, that converge there

	and approach a straight line; so, I did it in a two-dimensional way using Geogebra." (E)
C6 – Specific pedagogical technological knowledge	P3U22: "[...] from the moment we had these discussions—and I believe that the software helped them to see that relationship: as you progress in the sequence, you get closer and closer to the supposed limit" (E) P3U23: "I build a sequence using this formula, but the sequence will plot only natural numbers. There is a command that creates a sequence in Geogebra." (O) P3U24: "You put the expression, the variable, what value it contains, initial and final value. It will calculate the terms of a finite sequence from that formula." (O)

Some of P2's speech analysis units demonstrate information about the content that would be associated with the purpose of teaching. Due to the teacher's experience in the discipline of the undergraduate course, P2 finds this concept important to constitute the knowledge of future teachers, demonstrating, at first, mobilization of the CK linked to the PCK and making the intention to develop mathematical concepts clear.

With the strategy used in the observed class (exploration and discussion tasks), P2 directed the conversations with the students using open questions for a better understanding of the concept.

Note that the teacher has a conception of the students' knowledge and the deficit regarding the mathematical concept. Based on this conception, and with the support of the technological resource that students are familiar with, the teacher structured the practice to face this problem. The DICT was used only in the part of the class for graphical visualization of the sequence. The selected DICT assists the work with the mathematical content because it can work the concepts in a different way.

P2's knowledge of DICT diversity appears to be limited. Although the teacher finds them interesting, they are not often used. When P2 started using Geogebra it was in an expositive way, without changing the practice. However, in the observed class, the teacher's knowledge of Geogebra, specific to that content, enabled the visualization of the sequence, showing that it was possible to use it in the classroom.

We point out that P2 understands which technological resource was important to initiate discussions, visualize the concept, and optimize the work.

Visualization may have favored the discussion task, but the use of DICT was limited to that.

As for P1, it was possible to collect data on the broader use of technologies by the teacher. It is noteworthy that P2 does not demonstrate in-depth knowledge about this specific technology or about other DICT, despite using the software for the specific content of the class to allow new visualizations and expand the understanding of mathematical knowledge, as illustrated by the following units of meaning:

> *P3U14: "As soon as I started here at the IF, the teaching degree course began, I gained interest [in DICT] precisely to be able to do things with students. [...] Thais (teacher with fictitious name) already used Geogebra with a certain proficiency and then I thought 'I need to learn too,' right? And then I started to use it. I started to use it, but then I stopped. I didn't use Geogebra again for a while. I would say for a few years, even. I think that I came back to it this year because of the stimulus of the research, so I started to work with it again." (E)*
>
> *P3U15: "[...] one of the proposals of the discipline is for them to know how to use a software, including Geogebra. So, I had to start working with Geogebra, because one semester I had this discipline, however, then, the use of Geogebra was more in the sense of teaching them how to use Geogebra. More in the sense of teaching them how to handle it. Then, I had to learn some things by exploring it myself, but after that it became inert. I only recently started using it again."(E)*
>
> *P3U16: "After this experience I would use it again, I think it was interesting." (E)*
>
> *P3U17: "Well, I use a projector when I work on something expositive, then, I use PowerPoint or Latex to design something and that's about it. The use I make from technologies is very limited. Sometimes we also use cell phones because, because I propose group discussions and, in some situations, they have cell phones at hand, so they end up researching something to answer the question or to discuss it with colleagues." (E)*
>
> *P3U18: "I applied Geogebra, whenever possible, to see if maybe they could understand the content better. But it was in*

> *that expositive way, the practice was nothing different, the only difference was that I was using the software instead of Power Point." (E)*
>
> *P3U22: "[...] from the moment we had these discussions—and I believe that the software helped them to see that relationship: as you progress in the sequence, you get closer and closer to the supposed limit" (E)*
>
> *P3U25: "After this experience, I'm even thinking about other things we could do using Geogebra." (E)*

Considering the TPACK as knowledge that carries a specific character for a technology and for a content to be addressed in a teaching proposal, it is possible to consider that, in this system, the teacher can mobilize the necessary pedagogical technological knowledge for that specific content. In a similar way, as the works related to the PCK point out, a teacher can have a developed PCK for one content and not for another content—with TPACK, we can trace the same line. Knowledge of a specific DICT, used to teach a specific content, can present a balance of knowledge in a given context. However, it is very restrictive because the teacher does not have options for other DICT or other contents. This aspect can lead to discussions about the use of PCK and TPACK as models for understanding professional knowledge, a fact that we will discuss next.

Some conceptions can be related to the findings of P2. For this teacher, the content to be worked on in the classroom and what pedagogical practice is used in teaching are well defined (C1 and C2). We found evidence in the category C4, C5, and C6 that P2 does not master and does not use many technological resources in class; the use of DICT in the observed class was directed to a specific resource and only for concept visualization; which indicates a certain distance between technological knowledge and the teacher's teaching practices. Thus, it is hard to say that there is a deep integration of technology.

The data analyzed in the lesson plan, CoRe, and SCoRe described P2's pedagogical knowledge about the adopted strategy and demonstrated that the teacher recognizes the place of the content, the importance of student's understanding, and the limitations that the students carry regarding the concepts. In this way, knowledge related to experience, including within the institution, demonstrates that P2 integrates pedagogical and content knowledge to work with the specific concept of our observation.

The data collected in interviews and observation of P2 class indicate that this subject does not demonstrate mastery of different technologies for classroom use nor having extensive experiences with the specific used resource.

The DICT choice, in the case of P2, was intended to solve a specific problem that P2 considers important in the training of mathematics teachers, something present in the context, as demonstrated by the listed units.

DISCUSSIONS ABOUT THE ANALYSIS

With the observation of the collected data, we believe it is possible to make some interpretations and inferences about how teachers' professional knowledge of DICT use is integrated with the content and pedagogical practice. It is possible to understand aspects of how technology appropriation can generate different actions and allow the mobilization of professional knowledge.

We observed that the greater the technology appropriation, the greater the ease of incorporating the use of resources into the classroom environment; and, in these cases, the greater the integration between technological, pedagogical, and content knowledge.

Teacher P1 presented a broader knowledge and a more general view of technologies, as well as the selected DICT for the observed class. As a consequence, P1 acted to integrate DICT use with the specific content, so that the resource would allow a different approach to the theme when compared with an approach without a technological tool.

When observing P2, the teacher did not show a high level of broad technology appropriation in the interview. However, the analysis of the class and other materials recognized the knowledge that makes up the TPACK (except for general technological knowledge) and the proposal incorporated specific technology to pedagogical and content knowledge.

Our interpretation considers that the specific knowledge of a given technology allows its use in the classroom, even when the teacher does not have a wide repertoire of knowledge about other technologies, which explains the specific character imposed by the TPACK model (specific technology – specific content – pedagogical knowledge). When referring to PCK, we can say that a teacher can present a high PCK for a specific content and a low PCK for another, a fact that characterizes the specificity of the construct regarding content (Leal, Novais and Fernandez, 2015).

Similarly, for TPACK, we can consider that a technology associated with a specific content can produce an integration of knowledge by a teacher, even if the teacher does not master any other resources.

Returning to the discussions proposed by Cox and Graham (2009) and aligning it with the question of content specificity of pedagogical and technological knowledge, we interpret that, even in a scenario of low technology appropriation, the use of technologies integrated with pedagogical knowledge is possible and conceivable. However, this limits the incorporation of technological resources in other teaching contexts (other content, other students, for example). In this perspective, it is possible to recognize this dynamic in the TPACK model, which shows possibilities for the formulation of training strategies. As the authors point out, in scenarios in which DICT are not yet consolidated, the TPACK perspective works as a tool to develop teacher training and formation.

Thus, we believe it is possible to debate the relationship between technology appropriation and TPACK. In its design, the construct reflects that technology appropriation, combined with the use of technological knowledge for teaching, contributes to TPACK. However, the previously discussed specificity seems to question this premise.

Technology appropriation can help incorporate the practice in a more natural way and consolidate the TPACK with different technologies and concepts, an aspect pointed out by the creators of the construct (Mishra and Koehler, 2006)

Another significant aspect refers to the importance of non-technological knowledge—directly linked to the PCK. Both teachers described the knowledge of students, teaching contexts, and classroom management. With developed PCK domains, the integration with technological knowledge seems favorable in scenarios with both greater technology appropriation (P1) and with less technology appropriation (P2). Still, in the first case, since the technology is already incorporated into the professional practices of the teacher, we question whether the PCK encompasses the use of already incorporated resources. Such reflection can be discussed to adapt the models of professional recognition to the different research scenarios.

Considering these specific scenarios, it is important to reflect that the use of DICT in teaching can be incorporated in different ways since current digital technologies do not have specificity and are unstable due to rapid

evolution, which makes reflecting upon its use increasingly necessary before incorporating them into teaching practice. As Moran points out:

> (...) teachers can find their most appropriate way to integrate the various technologies and the many methodological procedures. But also, it is important that they expand them, that they learn to master the forms of interpersonal/group communication and those of audiovisual/telematic communication. (Moran, 2000, p. 32) [free translation]

It is also necessary to question the issue of generality from the TPACK perspective, since the development of professional knowledge for teaching that considers the use of technological resources depends on the specificity of the theme and of the technology itself.

Thus, from the perspective of our data and the adopted framework, it is possible to consider that the in-depth knowledge of a single resource for classroom use can identify a high TPACK for a professional, while the broad knowledge of numerous resources, without the focus on teaching, can identify a professional with undeveloped TPACK.

CONCLUSION

Considering our general objective of investigating how professional knowledge of DICT is integrated with specific content and pedagogical knowledge in professional practice, we can understand that, even though the used methods and model do not deeply investigate knowledge, professional knowledge is shown in practices. In general, the practice and the reflections (before and after practice) compose the process of recognition of the mobilized knowledge.

In the observed classes, we verified that the class was given as described in the plan, CoRe, and SCoRe with a certain tranquility, which may be related to the pedagogical content knowledge. We recognized in all teachers their knowledge regarding teaching (PK, TPK, PCK, TCK), an essential factor for class development.

When looking at the TPACK domains of knowledge, we observed technology appropriation interconnected with the TK aimed at potential teaching proposals, associated with the TPK and TCK, in the practices of the investigated subjects, with more or less emphasis.

In the case of P1, the vast technology appropriation may have favored the integration of DICT to the specific content, allowing a new approach. However, in the case of P2, the teacher does not have a wide knowledge and use of technological resources, as stated in the interview, even though we observed the integration of a specific DICT with a specific content. Although there is no vast domain of technology, it was possible to observe a TPACK domain due to the application of a DICT in a specific content and pedagogical context. Perhaps the TPACK of that teacher may not be recognized when working with a different content or technology. The TPACK construct allows the verification of this type of specificity, contributing to the interpretation of this type of scenario, such as P2. Thus, it can encourage training practices to strengthen categories that do not yet have training actions associated with the use of DICT.

This fact agrees with studies on TPACK, and it is also the subject of studies that seek to promote the development of professional knowledge. Thai is, different studies show concern with the development of technology appropriation themes that go beyond the learning of a specific technology (Harris and Hofer, 2015; Alcântara, Dullius and Carreira, 2016).

In the case of P2, we can use the TPACK model, but we recognize the importance of the PCK perspective. When it is clear that the teacher masters a DICT, one can contribute to research and development of training proposals by verifying the use of this knowledge linked to the reflective process and the mobilization in the PCK in action and collective PCK (proposed in the Refined Consensus Model for the PCK) or even by considering DICT as a category of knowledge within pedagogical knowledge.

Thus, some considerations can be made:

1. Pedagogical appropriation is, in fact, related to the way professionals develop their practice and incorporate technological knowledge to pedagogical and content knowledge.

   According to Mishra and Koehler (2006), a new technological knowledge can generate an imbalance in other knowledge and "the addition of a new technology is not the same as adding another module to a course. It often raises fundamental questions about content and pedagogy that can overwhelm even experienced instructors." (Mishra and Koehler, 2006, p. 1030)

2. The TPACK proposal carries specificity related to technology and content. Thus, even if the level of technology appropriation is not high, it is possible to recognize a specific TPACK in a practice.

   This only reinforces the importance of working with continuing education aimed at the use of technological resources, helping cases such as P2; which agrees with several mentioned studies on continuing education (Cyrino; and Baldini, 2017; Koehler and Mishra , 2005; Harris and Hofer, 2015).

3. The PCK and TPACK constructs are not exclusive, but complementary. Different scenarios are present in an educational environment: professionals who have extensive technological knowledge, but do not use them in the teaching-learning processes; professionals who have such knowledge integrated with pedagogical practices; and professionals who do not have technological knowledge or have it for few resources. In this broad spectrum, the recognition of professional knowledge to promote training actions can be supported differently by both constructs.

We recognize the need for a wider range of investigations to relate other knowledge mobilized by teachers during their practices, to list the encountered difficulties in each context, or to focus on student learning. We believe that this research can present data and interpretations that add to the literature, in order to move forward in the construction of formative proposals and contribute to the field of teacher training focused on the use of technological resources.

AUTHORS' CONTRIBUTIONS STATEMENTS

The authors LCV and GGJ were responsible for conceptualization, data curation, methodology and validation. LCV performed the field research (investigation) and writing – original draft and GGJ performed the supervision and writing – review & editing.

DATA AVAILABILITY STATEMENT

The data supporting the results of this study will be made available by the corresponding author, LCV, upon reasonable request and provided they are not contrary to the assumptions of the project submitted to the Ethics and Research Committee.

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