Epistemological reflections of the teachers' specialized knowledge model: Chemistry teaching in focus

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ABSTRACT

The theoretical model Specialized Knowledge of the Mathematics Teacher (MTSK), which corresponds to the Specialized Knowledge of Mathematics Teachers, has been not only the theoretical reference in research on the teaching and learning of Mathematics, but also, due to its specialization, as a reference model for other areas of knowledge, such as Physics, Chemistry, Biology, Portuguese, History, among others. The purpose of this article is to discuss the use of the MTSK theoretical model as a theoretical framework in the proposal of models for other areas of knowledge such as Chemistry, based on the epistemology of these two sciences. Qualitative research is assumed as a method, and its classification in relation to the objectives is the explanatory approach and in relation to the technical procedures the bibliographic approach. In this way, the development of the article begins with the presentation of the theoretical model of Mathematics, including the epistemological view attributed by the researchers when proposing this model. Subsequently, the Specialized Knowledge of Chemistry Teachers (CTSK) model proposed by the MTSK is presented. Finally, it ends with the epistemological vision that made this transposition between the models possible without losing the specialized character for both areas.

Keywords: Teachers' knowledge, Teaching chemistry, Theoretical model, Bachelard.

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INTRODUCTION

In the 80's, the publications of Shulman (1986, 1987) on *Pedagogical Content Knowledge* (PCK) was an important milestone for education, the model contributed to the determination of professional knowledge, presenting educational aspects capable of contributing to student learning, through seven basic categories of knowledge (Content Knowledge; General Pedagogical Knowledge; Curricular Knowledge; Pedagogical Knowledge of the Content; Knowledge of Students and their Characteristics; Knowledge of Educational Contexts, and; Knowledge of Educational Purposes, Purposes and Values, and their Philosophical and Historical Foundations).

After 27 years of the first publication of the PCK, a survey pointed out that the area of Mathematics had the highest prominence of publications with the PCK being 739 works published, in descending order of areas investigated, followed by Sciences with 607 works, Chemistry with 154, Physics 111, Biology 83 and Environmental 24, and Astronomy 19, respectively (Goes, 2014).

During this period, the Mathematical Knowledge *for Teaching (*MTK) model was published by (Ball; Thames; Phelps, 2008), with studies carried out from the PCK and which, due to gaps found in the model, made it possible to propose a theoretical model called *Mathematics Teacher's Specialized Knowledge (MTSK*) by the Ibero-American MTSK Network (Carrillo *et al*., 2014; Carrillo *et al*., 2018).

Thus, the general objective of this article is to explain a discussion about the use of the theoretical model Specialized Knowledge of Mathematics Teachers (MTSK) as a theoretical framework in the proposal of models for other areas of knowledge such as Chemistry. The specific objectives are: to search the literature on the difference between Science, Mathematics and Chemistry; analyze Bachelard's epistemological view of different types of knowledge, and; check if there has been a loss of the specialized character in both models. In this sense, the research method is the qualitative research, and its classification in relation to the objectives is the explanatory approach and, in relation to the technical procedures, the bibliographic approach. The treatment of the results was expressed through the interpretation and systematic confrontation in the transposition of the model of Specialized Knowledge of Teachers of Mathematics to Chemistry, based on the arguments of Bardin (1995), that is, obeying the phases of pre-analysis of the analysis material, the exploration of this material with the classification and, subsequently, interpretation of the data and systematic confrontation.

Next, the theoretical model of Mathematics and the epistemological basis attributed by the researchers of the MTSK Ibero-American Network are presented, in the second moment, the model of the Specialized Knowledge of Chemistry Teachers (CTSK) is highlighted,[6] which was proposed having the MTSK as a theoretical reference base. In short, the article will present the epistemological

[6] Chemistry Teacher's Specialized Knowledge.

view between Mathematics and Chemistry to justify the possibility of using MTSK as a theoretical basis in the proposal of the model for the area of Chemistry.

EXPERT KNOWLEDGE OF MATHEMATICS TEACHERS

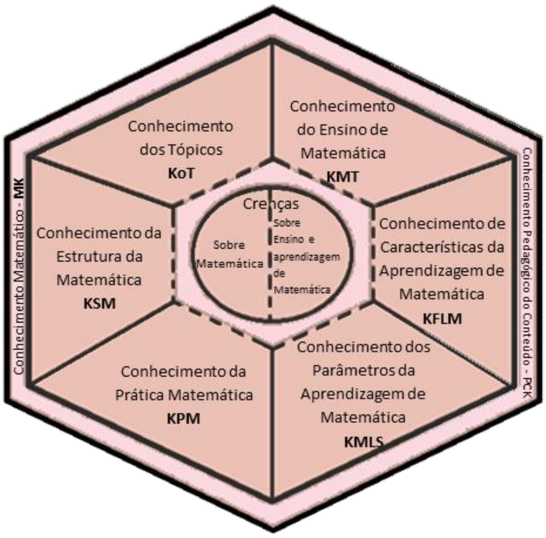
In the 90's, research with Mathematics Education began at the University of Huelva with a focus on teaching and learning, problem solving and understanding the knowledge of Mathematics teachers (Carrillo *et al*., 2022), based on the line of research presented by Shulman (1986, 1987) in the 80s, with the application of the Pedagogical *Content Knowledge (*PCK) model, and later, working with the model developed exclusively for the area of Mathematics, being the Mathematical Knowledge for Teaching, Mathematics *Knowledge for Teaching (*MTK) of (Ball; Thames; Phelps, 2008).

However, due to gaps, for example, in the characterization of subdomains through actions and not teacher knowledge, identified years later with the models worked up to that moment, there was then the first proposal of the specialized theoretical model for teachers, which was called Specialized Knowledge of Mathematics Teachers, *Mathematics Teacher's Specialized Knowledge* (MTSK) of (Carrillo *et al*., 2014). The MTSK is a theoretical model that describes the set of specialized knowledge that is fundamental to teach a given mathematics content (Carrillo *et al*., 2014; Moriel Juniore Wielewski, 2017; Carrillo *et al*., 2018).

The Specialized Knowledge of Mathematics Teachers model is divided into three domains, so that each domain has its subdomains and each subdomain can be further divided or not into categories (Carrillo *et al*., 2018).

The Mathematical Knowledge (MK) domain and the Pedagogical Content Knowledge (PCK) domain have three subdomains each. MK with: i) Knowledge of Topics (KoT), ii) Knowledge of the Structure of Mathematics (KSM), and, iii) Knowledge of Mathematical Practice (KPM). On the other hand, the PCK domain, with i) Knowledge of Mathematics Teaching (KMT), ii) Knowledge of Mathematics Learning Characteristics (KFLM) and, iii) Knowledge of Mathematics Learning Parameters (KMLS), respectively. The Beliefs domain, which is located at the center of the model, aims to demonstrate that it permeates all the knowledge of the other domains and is divided into beliefs about Mathematics and about the teaching and learning of Mathematics, as shown in figure 1 (Carrillo *et al*., 2018).

Figure 1 – MTSK model.



Source: Carrillo *et al*. (2014).

The categories are divisions of the subdomains and are present so far, only in the subdomains referring to the domains of Mathematical Knowledge and Pedagogical Knowledge of Content, emphasizing that not all subdomains have categories and there are no rules of the number of categories that each subdomain can have, it is the result of research proposed so far, as shown in Table 1 (Carrillo *et al*., 2018).

Table 1 – MTSK model with definition of subdomains and categories

Domains	**Subdomains**	**Categories**
Knowledge Mathematician	KoT – Knowledge of Mathematical Topics	1. Procedures (How to do? When to do it? Why is it done this way? Characteristics of the result) 2. Definitions, Properties, and Fundamentals 3. Impersonation Registration 4. Phenomenology and applications
	KSM – Knowledge of the Structure of Mathematics	1. Connections based on simplification 2. Complexity-based connections 3. Auxiliary Connections 4. Cross Connections
	KPM – Knowledge of Mathematical Practice	-
Knowledge Pedagogic of the Content	KMT – Knowledge of Mathematics Teaching	1. Theories of Teaching Mathematics 2. Didactic resources (physical and digital) 3. Strategies, techniques, tasks, and examples
	KFLM – Knowledge of the Characteristics of Mathematics Learning	1. Theories of mathematical learning 2. Strengths and difficulties in learning math 3. Ways for students to interact with mathematical content 4. Prospect of Interest in Learning Mathematics
	KMLS – Knowledge of the Parameters of Mathematics Learning	1. Learning Expectation 2. Expectation of the level of conceptual or procedural development 3. Sequence of topics

Source: Carrillo *et al.*, (2018).

The MTSK Ibero-American Network, currently coordinated by Professor Dr. Núria Climent, but previously coordinated by Professor Dr. José Carrillo, when proposing the theoretical model on the Specialized Knowledge of Mathematics Teachers, considered it important to present the epistemological view for a better understanding of Mathematical complexity, its limits and ambiguities, not only analyzing what the literature presents, but deepening in the sense of understanding the "why" (Carrillo *et al.*, 2014). Thus, the consideration of specialized refers to a style of knowledge, not focusing on the sum of the parts of knowledge, nor "what" the teacher knows, but focusing on "how" knowledge exists for the Mathematics teacher in the sense of a "whole" and its dynamic and complex interactions in the construction of the Mathematics teacher's knowledge, disregarding any types of fragmentations of mathematical knowledge, since such fragmentations would make interactions of knowledge and complexity impossible (Scheiner *et al.*, 2017).

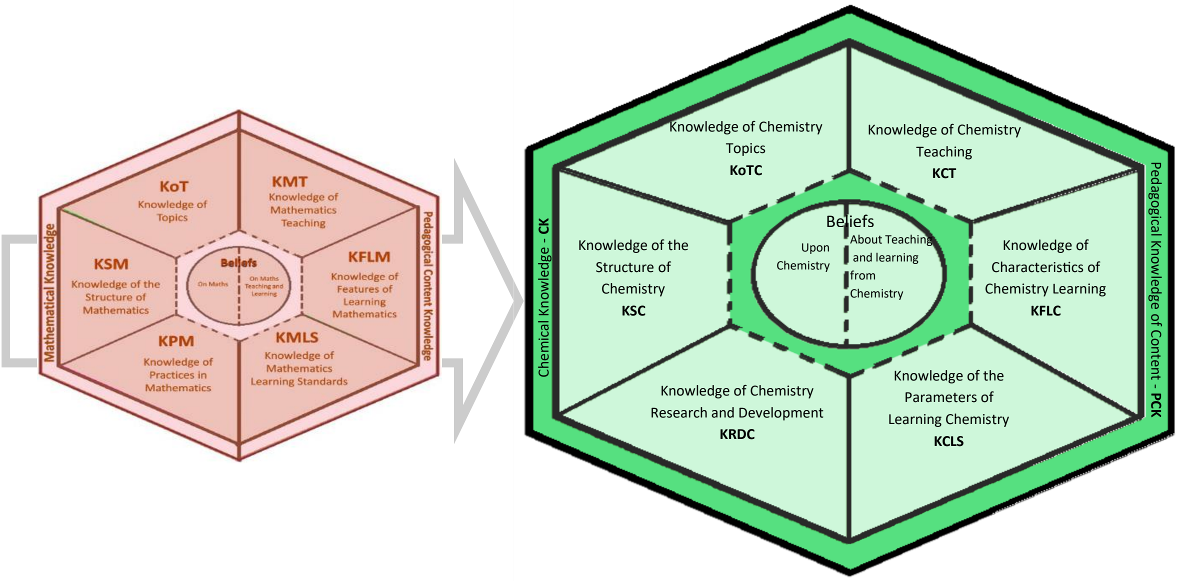
The Specialized Knowledge of Mathematics Teachers (MTSK) model, in general, has a socio-constructivist epistemological view, in which the authors consider the construction of knowledge, the beliefs that exist not only in intellectual activities, but also personal and social ones, as being important for human interactions and development. When considering the pedagogical focus and specialized knowledge of a teacher in the area of Mathematics is no different, it is considerable not only the teacher himself, but the entire context to which he is inserted and that there is no possibility of disregarding it, since there is psychological, cultural, social influence, personal interests, among other considerable issues (Carrillo *et al.*, 2014).

EXPERT KNOWLEDGE OF CHEMISTRY TEACHERS

The theoretical model Specialized Knowledge of Mathematics Teachers (Carrillo *et al.*, 2014), in recent years, has been a reference in research in the areas of Biology (Marques, 2020; Louis; Carrillo, 2020; Louis; Carrillo; Rocha, 2021), Physics (Lima, 2018), Chemistry (Soares, 2019; Martins; Carbo; Soares, 2021; Floriano, 2021), and Portuguese Language (Moreira; Silva; Evangelista, 2020).

In the area of Chemistry, a Chemistry Teacher's Specialized Knowledge *(CTSK) model was proposed, in* which the literature reports that the standardization of nomenclature in English was maintained, envisioning the internationalization of the model, as in the MTSK. The current model has a hexagonal format, with domains, subdomains, and beliefs that permeate the knowledge of the entire model (Soares, 2019; Soares *et al.*, 2020) (Figure 2).

Figure 2 – Model of Specialized Knowledge of Chemistry Teachers based on the MTSK



Source: Carrillo *et al*., (2018, p.6); Soares (2019, p. 77, adaptation).

The CTSK model (Chart 2) has the Knowledge of Chemistry (CK) domain, which has the following subdomains: i) Knowledge of Chemistry Topics (KoTC), which encompasses knowledge related to theories, concepts, definitions, models, formulas, representations, experimentation, applications, history of Chemistry, etc.; ii) Knowledge of the Structure of Chemistry (KSC), referring to the knowledge of the structure of Chemistry and the knowledge of the connection between different concepts, whether by complexity, transversal, auxiliary, experimental, applicability, simplification and/or representation connections; and iii) the Knowledge of Research and Development of Chemistry (KRDC), which includes the knowledge of Chemistry teachers regarding the investigative development of the area when generating new knowledge (Soares, 2019; Soares *et al*., 2020).

The second domain is called Pedagogical Content Knowledge (PCK), this domain also has three subdomains: i) Knowledge of Chemistry Teaching (KCT) referring to the knowledge of the Chemistry teacher regarding the use of certain resources, strategies and/or potentiality of a certain activity for a certain Chemistry content; ii) Knowledge of the Learning Characteristics of Chemistry (KFLC) which refers to the knowledge of the Chemistry teacher about the assimilation process, interests, errors and/or difficulties of a Chemistry content; iii) Knowledge of the Chemistry Learning Parameters (KCLS), which includes the knowledge of the Chemistry teacher regarding the curricular parameters (Soares, 2019; Soares *et al*., 2020).

Table 2 – CTSK model with domains and subdomains keeping the acronyms in English

Domains	Subdomains
Knowledge Chemist	KoTC – Knowledge of Chemistry Topics
	KSC – Knowledge of the Structure of Chemistry
	KRDC – Knowledge of Chemistry Research and Development
Knowledge Pedagogic of the Content	KCT – Knowledge of Chemistry Teaching
	KFLC – Knowledge of the Learning Characteristics of Chemistry
	KCLS – Knowledge of the Parameters of Learning Chemistry

Source: Soares (2019).

EPISTEMOLOGICAL REFLECTIONS BETWEEN MATHEMATICS AND CHEMISTRY

Analyzing the epistemological knowledge it is possible to highlight in the area of Mathematics the importance of Pythagoras, even in the sixth century B.C., for the evolution of this science, he provided significant contributions to the area since he proposed important concepts not only in the numerical aspect, arithmetic theories, but also in the determination of even and odd, in the rational proof of the theorem called Pythagorean Theorem, He proposed the musical unit of measurement and, among countless contributions, still influenced scholars centuries later. Although Pythagoras is well known in Mathematics, Thales of Miletus also had his contributions, but related to proportional segments, and the literature reports that his considerations were directly related to the application of mathematics in the face of some real difficulty that he faced in his daily life (Huisman, 2001).

Centuries later, among many scholars who stood out, the influence of Galileo Galilei stands out, who exchanged the studies of Medicine for Mathematics due to the interest aroused by the works of Archimedes and Euclid. Galileo dedicated himself to the application of mathematics through geometrization in Physics and Astronomy, collaborating with important knowledge, abandoning the qualitative conception used to explain the facts, for a new proposal of explanation of phenomena through observation, experimentation and Mathematics, corroborating with the construction of important knowledge for science (Andery *et al*., 1996).

Still considering the characteristics of the area of Mathematics, it is worth mentioning that due to its own language, it is a science with a high level of abstraction, but if contextualized to the resolution of real problems it can build meaning to knowledge (Carrillo *et al*., 2014). This statement is in line with the point of both Comte (1978), who in his work argues that Mathematics is more generalized, and Bachelard (1996), who points out that Mathematics is beyond a simple geometric description.

Comte (1978) also presents some differentiations of the sciences, in which Physics is concerned with studies of heat, force, light, etc.; Chemistry studies different subjects, complementing with Laplace's contribution to explain chemical phenomena and their positive influence that was significant for the progression of Chemistry as a science, and; Biology, with studies of vital phenomena and their organization and interaction, making it clear that each science studies only a certain group of phenomena.

Borrego *et al.,* (2004) in their work, present a practical example of the differentiations of the sciences, indicating what would be the responsibility of study related to each area. The authors consider as an example a natural system, in which Chemistry would be the area responsible for the studies of the composition of the environment, Biology would be responsible for the studies of living and dead particles and their respective interactions with the system, and Physics would be responsible for the study of the set of particles as materials.

Although these sciences use Mathematics for a rationalist explanation of phenomena, in the area of Chemistry there is also the chemical language, used to describe chemical phenomena, for example, symbols, chemical equations, reactions, models, structural formulas, etc (Roque; Silva, 2008), a language distinct from the mathematical language, but also a language, and for chemistry both are necessary, both to explain its phenomena and to represent them, both at the macroscopic and microscopic levels (Oliveira *et al*., 2015).

During his investigations, Bachelard noticed that the contribution to the area of Chemistry should be cautious, to avoid problems with publication, so he adopted a strategy of neither pronouncing nor evidencing the word "atom", although he was a chemical philosopher (Huisman, 2001), so in his works it is common to find examples referring to the area of chemistry, but not directly evidenced.

Bachelard also contributed to the differentiation of knowledge, for him all knowledge is an answer to a question, and it cannot be an opinion or a generalization, since both are dangerous, delay the progress of knowledge, are an obstacle to scientific thinking and harm scientific culture, so through the proposal of problems, There is the construction of knowledge, through experimental observation, linking scientific thought to empiricism and rationalism, providing an evolution of science. Bachelard also discusses in his work the ruptures between common and scientific knowledge as scientific progress (Morão *et al*., 1984).

Chart 3 – Summary of the epistemological position of Mathematics and Chemistry.

	Mathematics	Chemistry as a Science
Pythagoras	Arithmetic theories, determination of even and odd, in the rational proof of the Pythagorean Theorem, musical unit of measurement, etc.	
Thales of Miletus	He proposed proportional segments.	Mathematical application in real difficulties in various areas.
Galileo Galilei	He had a background in mathematics.	Geometrization in Physics and Astronomy, experimentation, observation and mathematical application.
Comte	Mathematics is more generalized, the Laplace Transform is an example.	Chemistry studies different subjects and with the Laplace transform we have the explanation of chemical phenomena, a significant influence on the progression of Chemistry as a science.
Bachelard	Mathematics is beyond a simple geometrical description.	Difference between knowledge, opinion, and generalization; theory and practice provide evolution of science; influenced epistemological ruptures; and is considered one of the fathers of constructivism.
Carrillo *et al.*	Science with a high level of abstraction, however, if contextualized to the resolution of real problems, can build meaning to knowledge. The MTSK has a socio-constructivist epistemological view.	
Roque; Silva		The sciences use mathematics for a rationalistic explanation of phenomena, and; the chemical language, used to describe chemical phenomena.
Oliveira *et al.*		Chemistry uses mathematical language and chemical language to explain its phenomena.

Cast Iron: Silva (2022); Oliveira *et al*., (2015); Carrillo et al., (2014); Castling; Silva (2008); Huisman (2001); Andery et al., (1996); Bachelard (1996); Morão *et al*., (1984); Comte (1978).

FINAL THOUGHTS

Through the analysis of the literature survey, the MTSK mathematical model has a socioconstructivist epistemological view, it has its own language, its specialized character is due to the non-fragmented knowledge of the Mathematics teacher, attributed to the knowledge of mathematical complexities and dynamics, and the application of mathematical knowledge is to obtain a rational explanation of real situations, that is, the application of mathematical theorems in another area of knowledge.

Analyzing the results related to the area of Chemistry, the literature pointed out that this science uses the mathematical language to explain its phenomena, but it has its own language that is also necessary to explain chemical phenomena, so that theory and practice (observation and experimentation) are necessary for the evolution of Chemistry as a science.

Confronting the results of Mathematics and Chemistry, one is an abstract science that needs to be applied in other sciences and the other is an empirical science that uses two languages (Mathematics and Chemistry) to explain its phenomena, respectively. Chemistry, although it uses the mathematical language, is not a science responsible for mathematical development, so it is up to the Mathematics teacher to know the complexity and development of it, to explain the concepts, definitions and mathematical laws to the students of the discipline, while the Chemistry teacher is attributed the competence to know the complexity of Chemistry before the use of both languages to explain its phenomena. for example, it is the knowledge of the Chemistry teacher when he identifies the possibility of using the Laplace Transform in explanations of chemical reactions, a mathematical theorem applied in Chemistry.

These differentiations pointed out by the literature demonstrate that the knowledge of the Mathematics teacher is different from that of the Chemistry teacher, so when the literature points out that the MTSK is socioconstructivist and Bachelard points out the differentiation between Mathematics that is not a simple geometric description and the Natural Sciences that need the mathematical language for a rationalist explanation, although there is also the need for observation and experimentation, it can be concluded that the specialized models will be different, and the Specialized Knowledge of Chemistry Teachers (CTSK) model was proposed from the theoretical framework the mathematical model (MTSK), was an important milestone, since Chemistry uses the mathematical language, although with a different focus from Mathematics, Proving the specialized character of both specialized models of teachers, MTSK and CTSK, it is also important to emphasize that the CTSK model can be used as an analytical tool in research related to Chemistry Teaching, as well as in teacher training and/or in the daily life of Chemistry teachers when planning and teaching their classes.

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