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Research on the Content, Technological, and Pedagogical Knowledge (TPACK) of Chemistry Teachers During Remote Teaching in the Pandemic in the Light of Students' Perceptions

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Abstract

Aim/Purpose	The objective of this study is threefold: (i) investigate how a group of subjects see the relationship between the integration of content, pedagogical and technological knowledge of their chemistry teaching in light of the teaching practices developed during the pandemic; (ii) present a framework for the integration of digital technologies in chemical education; and (iii) integrate empirical research on teachers' relationship with technology in the remote classroom during the pandemic.
Background	The COVID-19 pandemic has imposed changes in the ways of teaching and learning and has affected educational contexts at all levels of education. While technology has been instrumental in providing access to education during the pandemic, it has also revealed a picture of serious technological inequality, especially among students. The adoption of technology in education is an old topic in Brazil but still requires studies and advances in the implementation of Information and Communication Technologies (ICT) in education. With

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regard to teaching Chemical Science, the study of the skills and knowledge that teachers need to carry out an effective and efficient integration of ICT in education is still a priority at any educational level.

Methodology	The research method used was qualitative with an interpretive paradigm that involved 324 Licentiate and Baccalaureate students in Chemistry from public educational institutions in the five regions that make up the Brazilian territory. Data were collected through an online survey and, after being exported it was analyzed using Python software. In order to reduce the number of variables, exploratory factor analysis was carried out followed by a reliability analysis of the adopted factors, in addition to subsequent comparisons between the means related to the three factors for each of the categorical variables present in this work (Gender, Age, Region, Teacher Education, Period, and Course).
Contribution	This article analyzes the perceptions of these chemistry students in Brazil regarding the effective integration of content, pedagogical and technological knowledge of their chemistry teachers during the pandemic. It also proposes a framework of a model constituted from the amalgamation between Johnstone's triangle and the conceptual structure TPACK whose aim is to teach chemistry by interrelating the macroscopic, symbolic, and submicroscopic levels incorporated into technologies.
Findings	The results of this research allow us to conclude that of the three main knowledge areas proposed in the TPACK model, the field of Knowledge mostly Scientific of chemistry teachers (Factor 1) was pointed out as the most deficient when investigated in the light of the perceptions of the students. The model developed and presented in this study, which integrates TPACK into the Johnstone Triangle, proposed a theoretical framework that explains the integration of technology into the chemistry curriculum and gives teachers a very important role in its use and appropriation to facilitate the integration of technology in an effective way, thus adding improvements to the construction of chemical knowledge of their students.
Recommendations for Practitioners	This study found that it is necessary for chemistry teachers to carry out training courses to improve the development of ICT-related skills and, consequently, to use the knowledge that composes the TPACK structure in interrelated ways so that chemical instructions can be used in a pedagogically appropriate manner and effectively to improve students' chemistry learning experience.
Recommendations for Researchers	This study involved only higher education chemistry professors and students; therefore, future research is needed involving chemistry teachers from different levels of education to expand our results. In addition, the proposed model that integrates TPACK and Johnstone's Triangle can be reapplied and improved, and new theoretical and epistemological contributions can be added to the framework to improve the teaching and learning process of chemistry with the support of technologies.
Impact on Society	The understanding of the TPACK of higher education chemistry teachers in Brazil can demonstrate weaknesses in the process of incorporating ICT in the classroom during the process of teaching and learning chemistry. Therefore, this research typology can be useful in supporting the development of ICT-related skills, consequently improving teachers' TPACK. On the other hand, such understanding, by promoting reflections on university chemistry curricula, endorses the need for teachers' continuing education as a healthy mechanism for a growing integration of technologies in their teaching practices. The

	proposed model has the potential to align discussions on the use of technology in teaching chemistry, considering the specificities that are inherent and indispensable to the understanding of chemical knowledge.
Future Research	Future research should be to further improve the use of the proposed model that integrates Johnstone's triangle and the TPACK conceptual framework in teacher training, using it fully to guide the development and promotion of teacher training courses regarding the insertion of teaching technologies in a pedagogical way to teach chemistry in its different dimensions.
Keywords	chemical education, ICT, Brazil, teachers, TPACK, model

INTRODUCTION

As a consequence of the COVID-19 pandemic, drastic changes have occurred in teaching and learning. It has affected almost all aspects of the educational context and impacted all levels of education (Sahlberg, 2021). It brought with it a need to better understand the role of technologies and its human connections within the educational system which was not designed to promote remote teaching and, apparently, demonstrated that learning has been carried out in a space composed basically of a triad founded by teacher, students, and activities (Cleophas & Bedin, 2022; Silva et al., 2021). That is, there is a historical and specific design of the teaching and learning process in which the teacher holds the knowledge and, through activities, tries to pass it on to the students, above all, without direct or indirect relation to their context. While it is understood that the educational space is not easily moldable, during COVID-19 educators needed to adapt quickly and adopt new approaches. In many cases, emergency remote learning was implemented quickly as a way to try to mitigate the negative and still immeasurable impacts on student learning where learning could no longer happen face-to-face (Bedin & Cleophas, 2022; Sutton & Jorge, 2020).

In 2005, a conceptual framework was developed to propose the integration of technology with a focus on improving teaching and learning processes. This structure became known as Technological Pedagogical Content Knowledge (TPACK) (Koehler & Mishra, 2005), with the role of guiding the teacher's knowledge (Engida, 2014) in the integration of three domains of knowledge during a given instruction; that is, Technological Knowledge (CT), Pedagogical Knowledge (PC) and Content Knowledge (CK) (Koehler & Mishra, 2008). The intersections among these basic sets of knowledge domains give rise to four other different domains, the central intersection being called TPACK knowledge (Ribeiro & Piedade, 2021).

According to Koehler and Mishra (2009), to offer meaningful and highly proficient teaching, it is necessary that the simultaneous integration of each domain of knowledge occurs. After all, TPACK guides the teacher about the pedagogical insertion of digital technologies in the classroom with a view to scientific content, and not just about their operation and handling. It is the basis of knowledge about the complex multimodalities' relationships between pedagogy, content, and technology (Silva et al., 2021).

Nevertheless, the possibility should be considered that, at any time, the conceptual structure of the TPACK model may be expanded, essentially in its different types of integrated components, like the context, the formation, self-efficacy, and teaching beliefs, research objectives, and objects, experiences and knowledge, the students, resources, and school conjecture, to make it more explicit and operational. Therefore, as Soza (2020, p. 141) explains, it is necessary to pay attention to the implications of integrating technologies in teacher training beyond TPACK, presupposing "elements of the context related to the organization and structure of the institution, available resources, curriculum, educational actors, experiences, attitudes, and feelings, as well as the methodological and conceptual transformations."

In view of the above, the objective of this article is threefold. It aims to: (i) investigate how a group of subjects see the relationship between the integration of content, pedagogical and technological knowledge of their chemistry teachers in the light of the teaching practices developed during the pandemic to the analysis of the conceptual structure of Pedagogical Technological Content Knowledge (TPACK); (ii) illustrate a model aimed at teaching chemistry teachers based on the TPACK conceptual framework and Johnstone's Triangle; and (iii) integrate empirical research on teachers' relationship with technology in the remote classroom during the pandemic.

THEORETICAL FOUNDATION

It is known that there are several challenges involved in science education in the 21st century, such as social, cultural, economic, political, and pedagogical issues, that influence the methodological instruction of teachers and students (McFarlane, 2013). In this route, promoting the integration of Information and Communication Technologies (ICT) in chemistry teaching is still a complex topic when it comes to teachers (in practice and those still in training) since the planned insertion of classroom technologies is often discredited in the teaching and learning processes.

Indeed, student learning depends on the pedagogical approaches that teachers use in the classroom (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2018), although it is also known that the development of an effective pedagogy derives from several factors, such as teachers' strategies and resources in the progress of their classes, the interest of the students, and the available infrastructure. However, technology is increasingly gaining a prominent role in educational contexts. Especially after the COVID-19 pandemic, the existing relationship between technology and teacher has proved to be indispensable. UNESCO has been alerting for a long time to the importance of educational technologies, since it considers that, when inserted in the school environment, it should be seen as a systematic method to create, apply and define all educational and teaching processes that consider technical and human resources, in addition to their interaction. Nonetheless, it is necessary to consider that the articulation of ICT with educational practices initially depends on a personal decision (Costa et al., 2012).

Chemistry is an abstract science (Jong & Taber, 2007) and with regard to its teaching, the presence of representational levels during pedagogical instruction in the classroom is indispensable for full understanding. Johnstone (1991) proposed three representational levels for chemical science, making up the vertices of a triangle, considering the macroscopic, submicroscopic, and symbolic worlds, stating that the student must move shrewdly through them to demonstrate an expressive understanding of science and create models of explanation. The transition through these levels evidences a student's broad empirical knowledge since it requires cognitive agility between reading and interpreting a phenomenon to explain it scientifically through the representation of a model.

At the macroscopic level, the phenomenon is observed from its properties, emphasizing the student's context, given that it corresponds to observable and perceptible chemical processes in a visible dimension (Pauletti et al., 2014, p. 124). At the submicroscopic level, from specific models, the properties of chemical systems are explained based on the arrangements of your constituents (ions, atoms, and molecules). Finally, at the symbolic level, equations, codes, and symbols mathematically represent the phenomenon, both at the macroscopic and submicroscopic levels.

Like TPACK, Johnstone's triangle also acts as a pedagogical framework to guide teaching and learning and, when geared to the chemical universe, provides clear guidelines for everyone involved in chemical education (Reid, 2021). While experienced chemical teachers can fluently move between these representational levels of chemical knowledge, students, on the other hand, need help (Mahaffy, 2006; Schmidt, 2021; Taber, 2013; Talanquer, 2011). Both the model proposed by Johnstone (Figure 1A) and the conceptual structure that integrates TPACK, developed from Shulman's (1986) studies on Pedagogical Content Knowledge (Figure 1B), generate improvements in learning and student performance, in addition to guiding teaching actions during the elaboration of pedagogical instructions.

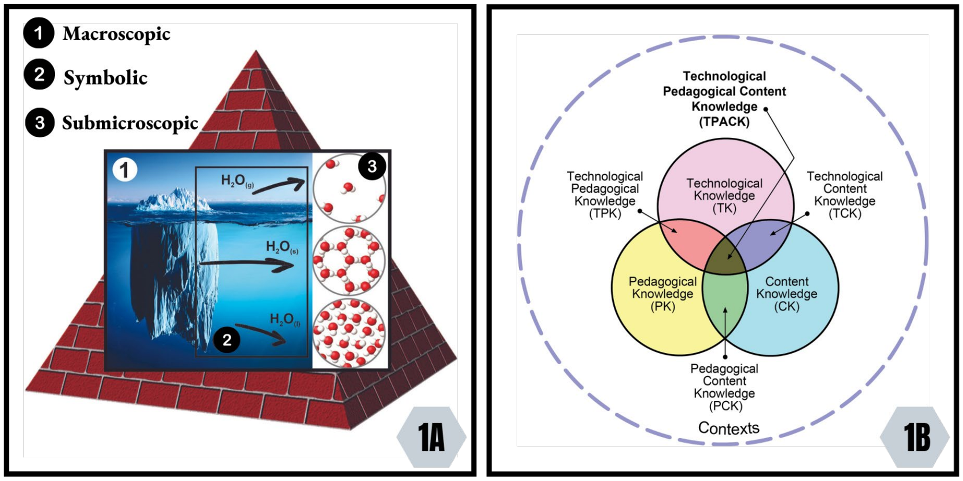


Figure 1. (A) Adaptation of the Johnstone triangle (Johnstone, 1982, 1991). (B) TPACK model based on http://www.tpack.org/

In view of this and considering the specificities of each model as well as their pedagogical intentions, it is possible to propose a fusion of them aiming at the integration of multilevel thinking in the teaching and learning processes of chemistry (Johnstone, 1991) in the light of TPACK. That is, inserting technology in a pedagogical way to develop scientific content in a chemical unit that considers the macroscopic, symbolic, and microscopic levels before the explanation of chemical phenomena, in order to increase the students' cognitive activity and the effectiveness of the learning process, becomes highly relevant and necessary (Sadykov & Čtrnáctová, 2019). Engida (2014) clarifies that TPACK is not a professional development model; it is a foundational structure for the teacher's knowledge which may be connected with the crucial representational levels for chemistry to be taught effectively, for example, by demonstrating to students its relevance to humanity, promoting interest, curiosity, and understanding about the vital concepts for their learning (Cardellini, 2012).

Figure 2 reveals a framework of the proposed model. It was constituted from the combination of Johnstone's (1991) triangle and the TPACK conceptual framework. In this model, all the intersections between the domains that make up the TPACK structure are maintained, as well as all the subdomains that arise from the interrelation between the domains referring to the Pedagogical Technological Knowledge (PTK), the Technological Content Knowledge (TCK) and the Pedagogical Content Knowledge (PCK). It is argued that TPACK needs to be present during chemical instruction and can contain the three representational levels (macroscopic, symbolic, and submicroscopic) to favor learning about chemistry, precisely because the teacher's knowledge regarding the content, pedagogy, and technology must be aligned with the representational levels proposed by Johnstone.

Since its publication, the chemical triplet proposed by Johnstone (1991) has been heavily reviewed by several authors. So, discussions about it are not watertight (Mahaffy, 2006; Taber, 2013). The macroscopic, submicroscopic, and symbolic levels are inserted with the other TPACK model intersections, making chemistry contents more flexible. This allows the teacher to move through the TPACK domains of knowledge, recognizing that macroscopic, submicroscopic, and symbolic level ideas must be intertwined with the effective use of the TPACK structure in order to promote the teaching which enhances students' learning: an effective pedagogy generating authenticity for the students and helping them improve their learning experiences in chemistry (Mishra & Koehler, 2006).

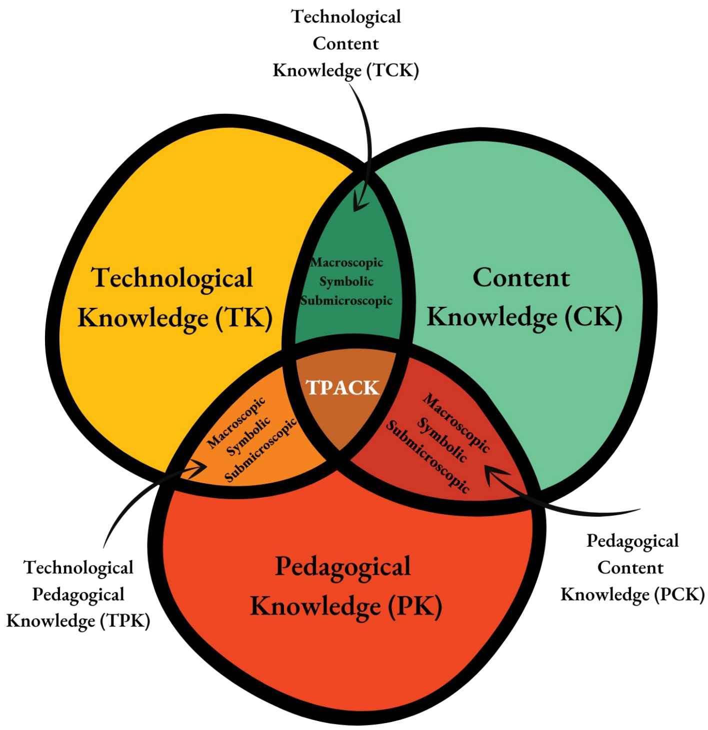


Figure 2. Integration between TPACK and Johnstone's (1991) triangle

Still on the proposition of a model aimed at chemical instruction, the notes of Maeng et al. (2013) were also adopted, considering that to be more effective. Educational technologies must be located in a flexible structure of content and pedagogy knowledge, as teaching chemistry effectively requires an understanding of its conceptual foundations as well as various strategies to overcome difficulties (Boesdorfer, 2019). Proof of this has been observed during the COVID-19 pandemic, given that it has impacted the teaching methods, implying the adoption of technologies on teaching and student learning (Babinčáková & Bernard, 2020; Canal et al., 2021; Mojica & Upmacis, 2022; Shidiq et al., 2021; Wijenayaka & Iqbal, 2021).

After all, it is understood that the teaching of chemistry should serve not only to constitute in the subject a scientific learning, shaped from the assumptions of Scientific Literacy and Technological Literacy but in the perspective of enabling the student with sufficiently human conditions so that the student can know and understand reality and himself/herself (Bedin, 2021). In view of the above, it is argued that in the proposed model it is possible to integrate technologies in teaching chemistry by considering its macroscopic, submicroscopic, and symbolic levels according to the specificity of the contents, although the conceptual understanding of chemistry ends up being provided most of the time through the submicroscopic and symbolic levels (Tsaparlis, 2009).

In the educational field, the successful integration of technology in chemistry teaching is directly related to flexibility to move through the fields of scientific, pedagogical, and technological knowledge. The integration of Johnstone's (1991) model in the classroom is directly linked to the teachers' knowledge, to their didactics, and in this context, to the employ of analogies and everyday examples to improve students' understanding of chemistry. In this way, the macroscopic level can be characterized as visible chemistry in which changes in the properties of matter can be described directly through the senses (e.g., changes in state, color, temperature density, and flammability), while the submicroscopic level is associated with the behavior of nanometric units such as atoms, ions, and molecules. The symbolic level, on the other hand, refers to the representation of macroscopic and submicroscopic phenomena, symbolically using mathematical and chemical equations, molecule formulas, diagrams, and so forth (Schmidt, 2021). Thus, the triangle representing the levels of description in chemistry helps to recognize the hindrances students have in learning, explaining macroscopic phenomena at a submicroscopic level (Abels et al., 2020), endorsing that there is a robust relationship between the TPACK theoretical model and the Representational Levels of Chemistry, since for the student to move through the different levels, the teacher's ability and competence is salutary.

Furthermore, while Pedagogical Technological Knowledge is central for the student to understand the macroscopic world of chemistry at a higher cognitive level (since in this field the teacher needs to demonstrate, through technology and pedagogy, the chemical world around the student, based on elements from their own daily lives), the Technological Knowledge of the Content is primordial for guiding the student's transition from the macroscopic level to the submicroscopic level, instigating the subject via appropriate (and chemical) software which emphasize, for example, the quantum nature of matter. Finally, to represent chemistry meaningfully through formulas, codes, and symbols, teachers need to master Pedagogical Content Knowledge to pedagogically teach the use of representational elements and mathematical calculations to describe a chemical reaction.

Apparently, the most complex level of integrating technology is the macroscopic level when referring to its experimental context. However, a study by Spyridon and Tsaparlis (2013) revealed that including simulations before a lab activity has become an effective way to improve problem-solving ability. The pivotal role of this level has as a priority the laboratory work whose purpose is to allow the adequate observation of the phenomena by the students. Although, it is quite common for students to fail while recording all observations as well as working memory overload (Tsaparlis, 2009). In order to resolve such problems, the use of technologies to support instruction at the macroscopic level has advantages for the educational context by reducing the costs of a safe and well-stocked chemistry laboratory. To this extent, technology is extremely versatile in chemistry, and it should not be excluded from the chemistry teaching process, as it has the potential to fill gaps in the development of laboratory skills (Achuthan et al., 2021). It is possible to use simulations, videos, mobile applications, games, social networks, software, and platforms, in addition to emerging technologies such as robotics, virtual, augmented, and mixed reality, among others.

RESEARCH METHOD

The research presented here fits into a study with a quantitative approach with a deductive bias, using a set of different statistical methods to constitute a standard of analysis, given the broad scope established.

PARTICIPANTS

Participated in this research, voluntarily, 324 students of higher education courses in Chemistry in institutions of public education, in the modality of bachelor and licentiate, from the five regions that make up the Brazilian territory.

PROCEDURES FOR DATA COLLECTION AND VALIDATION

In this field, the instrument for the construction of data was a questionnaire on the Google Forms platform, composed of two sections. In the first section, it was sought to probe the profile of the participants, considering the age group, the region of the country, the undergraduate course, and the identification of gender. The second section contained 21 assertions based on 7 levels of knowledge and distributed on a scale based on the Likert (1932) proposal, containing four scoring options ranging from lower scores (1 and 2), classified as strongly disagree and disagree, to higher scores (4 and 5) characterized as agree and strongly agree, respectively. It was chosen not to include a neutral point of the constructed scale to encourage a position on the part of the respondents (Cleophas & Cunha, 2020; Colton & Covert, 2007; Lucian, 2016).

The questionnaire was made available online through a link to different students of undergraduate chemistry courses, both licentiate and bachelor, from all over Brazil, through their course coordinators, and was in circulation for a week. For this process, by email, without any inclusion or exclusion criteria, professors and Chemistry Course Coordinators from Brazilian Universities were asked to participate by sending the online survey to their chemistry undergraduates. Therefore, it is not possible to measure the number of undergraduates reached (population). As the link to the online survey was sent by the coordinators, who had free will to select who to send it to, the response rate is unknown. Regarding the experiential educational context in which undergraduate students scored a grade for each of the 21 assertions (Table 1), it is stated that, due to the growth of infections by the SARS-COV-2 virus, it was developed entirely in a non-face-to-face manner, as the Ministry of Education (MEC; Ministério da Educação, 2020) granted Ordinance No. 343, of March 17, 2020, allowing educational institutions to develop their classes in digital media.

Table 1. Assertions used to identify TPACK in teaching practice

My teacher...
Content Knowledge - CK
(A) ... demonstrated sufficient scientific knowledge of chemistry.
(B) ... thought about the scientific contents of chemistry as an expert on the subject.
(C) ... deeply understood the scientific contents of chemistry.
Pedagogical Knowledge – PK
(D) ... was able to expand my thinking ability through challenging tasks.
(E) ... guided me to adopt appropriate learning strategies.
(F) ... was able to monitor my learning.
Pedagogical Knowledge of Content – PKC
(G) ... managed to deal with the most common misconceptions I had.
(H) ... addressed different teaching strategies to guide me in thinking and learning chemistry.
(I) ... managed, in different ways, to help me understand chemical knowledge.
Technological Knowledge – TK
(J) ... presented effective technical skills when using technologies in remote teaching.
(K) ... knew how to solve technical problems related to technology during remote teaching.
(L) ... used various internet tools and social media in his classes.
Pedagogical Technological Knowledge – PTK
(M) ... was able to use technology to insert myself into real-world situations.
(N) ... helped me to use technology and get data, plan and verify my learning.
(O) ... helped me use technology to build different forms of knowledge representation and to work collaboratively.
Technological Knowledge of Content – TKC
(P) ... used computer programs and software created for chemistry in his classes.
(Q) ... demonstrated knowing how to use technology to research chemistry.
(R) ... used different technologies to represent chemistry content in their classes.
Pedagogical Technological Knowledge of Content – PTKC
(S) ... taught classes combining technology, chemical content, and teaching strategies.
(T) ... with technology, enriched the classes and facilitated my learning in chemistry.
(U) ... showed technological knowledge, teaching strategies, and chemical knowledge.

That said, it is stated that from the second section of the questionnaire, the 21 assertions were used (Table 1) that were separated into named categories of factors, thus constituting a set composed of 3 factors (Table 3), namely: Factor 1: Field of Knowledge mostly Technological; Factor 2: Field of Knowledge mostly Pedagogical; and Factor 3: Field of Knowledge mostly Scientific. Furthermore, it should be noted that the data present in the Google Forms platform was downloaded into an Excel spreadsheet, considering ordinal data, to perform the analysis in Python (Millman & Aivazis, 2011), via pandas packages (McKinney, 2010), Matplotlib (Hunter, 2007) and Seaborn (Waskom et al., 2017), summarizing the data in tables and figures.

Analysis Procedures

Based on the profile of the research participants, and considering that it is heterogeneous in all dimensions, the Internal Consistency analysis was carried out through the calculation of Cronbach's (1951) Alpha Coefficient and the corrected item-total correlation coefficients for all items in the questionnaire. The maximum value of Cronbach's alpha is equal to the unity. Here it was calculated both globally (analyzing the entire construct) and after the elimination of each item, to assess its dependence on each item of the questionnaire. Values above 0.70 (Cortina, 1993) are indicative of good internal consistency for the use of the scale in the comparison between groups, whereas values greater than 0.90 are necessary for the use of the scale in the comparison between individuals. Additionally, the corrected item-total correlation coefficient quantifies the relationship between the item and the questionnaire's total score, with values between +1 and -1 (Zijlmans et al., 2019). Such quantities are shown in Table 2.

Table 2. Analysis of Cronbach's Alpha and the correlations between the assertions

Item	Cronbach's Alpha eliminating the item	Corrected total item correlation	Item	Cronbach's Alpha eliminating the item	Corrected total item correlation	Item	Cronbach's Alpha eliminating the item	Corrected total item correlation
A	0.947	0.314	**H**	0.943	0.719	**O**	0.943	0.753
B	0.948	0.287	**I**	0.943	0.705	**P**	0.945	0.597
C	0.947	0.322	**J**	0.944	0.672	**Q**	0.944	0.674
D	0.944	0.608	**K**	0.944	0.622	**R**	0.942	0.762
E	0.945	0.587	**L**	0.944	0.694	**S**	0.942	0.808
F	0.944	0.639	**M**	0.943	0.702	**T**	0.942	0.765
G	0.945	0.579	**N**	0.942	0.773	**U**	0.943	0.742
Cronbach's Alpha of the entire questionnaire: 0.947								

After evidencing the invariability of Cronbach's Alpha Coefficient (greater than 0.90) by eliminating each of the statements, the Exploratory Factor Analysis of the questionnaire was carried out to understand the best way to group its various items in the latent variables, thus impelling evidence for its validity. As the number of research participants was higher than recommended (300 subjects), combined with the fact that the ratio between the number of participants and the number of Likert items was greater than 15:1, greater than the recommended minimum ratio of 10:1 (Costello & Osborne, 2005), the analysis proved to be appropriate. Next, Bartlett's Sphericity test was performed to verify a possible correlation between the observed variables, using the comparison between the correlation matrix and the identity matrix. As a result [$X^2 = 5393$, $p = 0$], Bartlett's test presented a p-value equal to zero, indicating that the sample was statistically significant, that is, the observed correlation matrix differs from the identity matrix.

The following analysis took place through the application of the Kaiser-Meyer-Olkin (KMO) criterion, also known as the sample adequacy test, which analyzes whether the data set is capable of factoring. The result represents the degree to which each of the observed variables can be predicted, without error, by the other variables in the data set. After all, the KMO is an estimate of the proportion of variance between all variables, where the values are between 0 and 1; a value less than 0.60 is considered inappropriate. Thus, as shown in Table 3, the Global Value of KMO was 0.947.

Table 3. Analysis of the Kaiser-Meyer-Olkin criterion for each assertion

Item	KMO Value	Item	KMO Value	Item	KMO Value
A	0.868	**H**	0.950	**O**	0.937
B	0.864	**I**	0.940	**P**	0.961
C	0.837	**J**	0.932	**Q**	0.954
D	0.963	**K**	0.919	**R**	0.960
E	0.933	**L**	0.964	**S**	0.966
F	0.939	**M**	0.976	**T**	0.969
G	0.955	**N**	0.945	**U**	0.968

Considering that the values shown in Table 3 were above 0.80, the Exploratory Factor Analysis was carried out in *Python* (Persson & Khojasteh, 2021), using principal axis factoring as a factor extraction method, since the data showed a non-normal distribution by the Shapiro-Wilk test (Shapiro & Wilk, 1965). The rotation method chosen was the oblique rotation method, 'promax', as this allows the factors to be correlated. The choice of the number of factors can be performed using the Kaiser criterion or the slope graph, both based on eigenvalues. Using the calculated eigenvalues, a *Screeplot* was plotted, a graph that lists the eigenvalues in descending order, used to determine the number of factors to be retained in an exploratory factor analysis. The test, introduced by Cattell (1966), suggests keeping as many factors as there are eigenvalues before a "sharp bend" or "elbow" in the graph.

RESULTS

In Figure 3, the relationship between gender, age group, undergraduate course, and region of the country of research participants is presented.

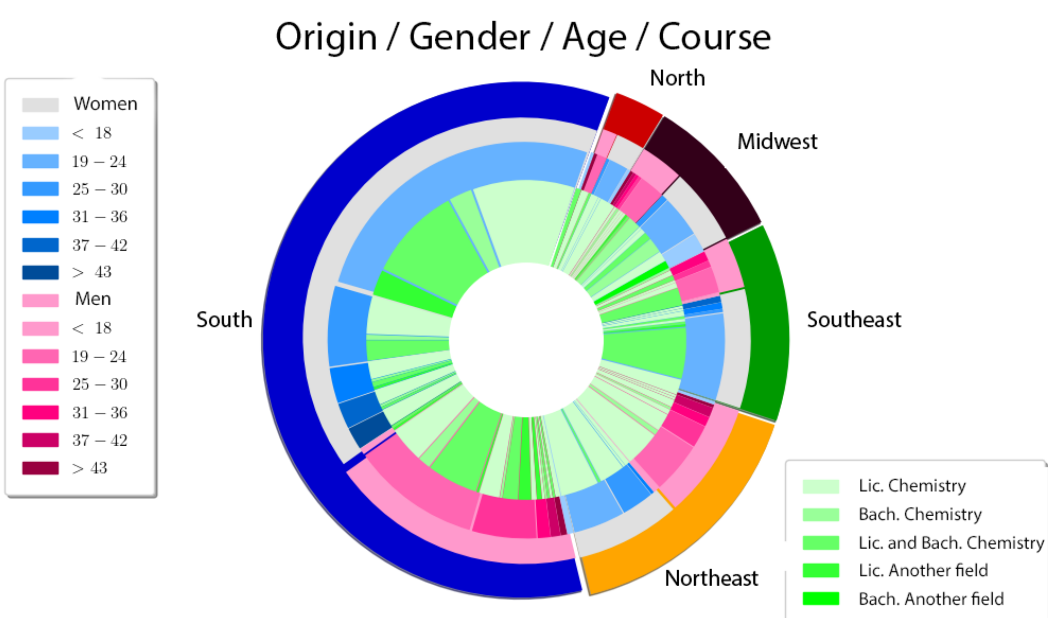


Figure 3. Relationship between the categories that expose the profile of the subjects

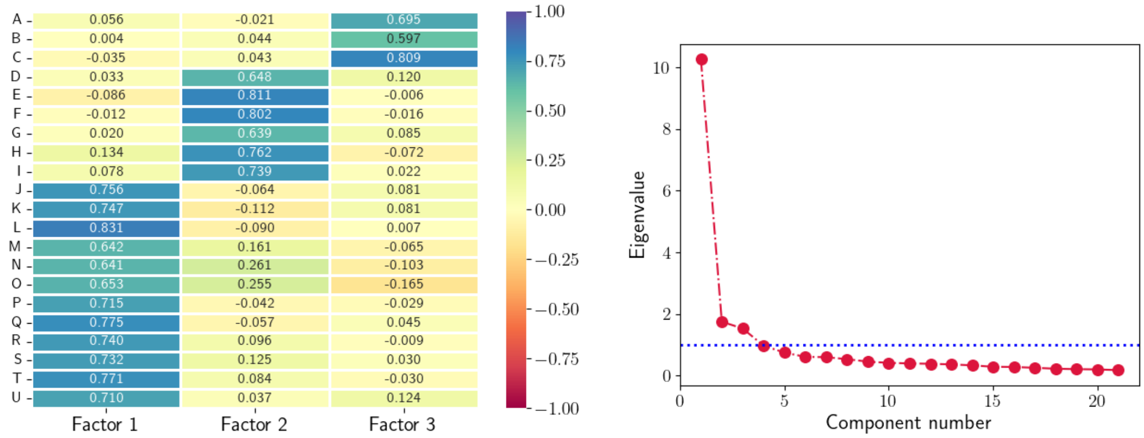
It is worth noting that Brazil is a continental country divided into five geographical regions: North, Northeast, Midwest, Southeast, and South. In summary, from Figure 3, it can be seen that 5.5% (n = 21) of the respondents are aged less than or equal to 18 years, with the majority (n = 8) from the southern region of the country and the feminine gender (n = 15). Subjects aged between 19 and 24 years comprise the highest percentage of the group (61.7%, n = 234), with the majority from the South region (n = 137) and females (n = 158). No different, females (n = 39) and the southern region of the country (n = 45) include subjects aged between 25 and 30 years (18.3%, n = 69). The southern region of the country also appears with the largest number of respondents for subjects aged between 31 and 36 years (6.6%, n = 25) and also for those aged between 37 and 42 years (4.7 %, n = 18), with females comprising the largest group (n = 14; n = 10, respectively). Finally, there is the group of subjects aged 43 years or older, which is represented by 3.2% (n = 12) of the group, 5 males (1 from the North region, 1 from the Northeast region, 1 from the Midwest region and 2 from the South region) and 7 females (South region). The south region of Brazil is the third most populated region in Brazil; therefore this is why it has the highest number of respondents. However, another possible reason for its higher representation in this study was that two (of the three) researchers in this study come from institutions located in the South, therefore potentially having a greater influence on the engagement of the respondents. All data are presented in Table 4.

Table 4. Distribution of survey participants by region, sex, and age

	Subgroups	**Number of respondents**
Sex	Female	243
	Male	133
	Other	3
Age	< 18	21
	19 to 24	234
	25 to 30	69
	31 to 36	25
	37 to 42	18
	> 43	12
Region	Midwest	34
	Northeast	61
	North	12
	Southeast	47
	South	225

From the heat map with factor loadings and the slope graph (Figure 4), the items were divided into three factors, which explain 54.66% of the total variance.

Based on what is shown in Figure 4, Table 5 was plotted, in which the three factors and the corresponding items of the instrument are presented. It is noteworthy that Factor 1 presents the Content Knowledge (CK), while Factor 2 presents assertions related to Didactics, with assertions D, E, and F intended for Pedagogical Knowledge (PK) and assertions G, H, and I refer to Pedagogical Content Knowledge (PCK). Accordingly, Factor 3 is related to the use of technologies, considering that assertions J, K, and L deal with Technological Knowledge (TK), assertions M, N, and O of Pedagogical Technological Knowledge (PTK), the assertions P, Q, and R of the Technological Content Knowledge (TCK) and the assertions S, T, and U of the Pedagogical Technological Knowledge of the Content (PTKC).



(a) **(b)**

Figure 4. (a) Heat map with factorial categories; (b) Slope graph

Table 5. Questionnaire factors and items

Items related to the statement: MY TEACHER ...	Load
Factor 1: Field of Knowledge mostly Scientific	**F1**
A: ... demonstrated sufficient scientific knowledge of chemistry.	**0.695**
B: ... thought about the scientific contents of chemistry as an expert on the subject.	**0.597**
C: ... deeply understood the scientific contents of chemistry.	**0.809**
Factor 2: Field of Knowledge mostly Pedagogical	**F2**
D: ... was able to expand my thinking ability through challenging tasks.	**0.648**
E: ... guided me to adopt appropriate learning strategies.	**0.811**
F: ... was able to monitor my learning.	**0.802**
G: ... managed to deal with the most common misconceptions I had.	**0.639**
H: ... addressed different teaching strategies to guide me in thinking and learning chemistry.	**0.762**
I: ... managed, in different ways, to help me understand chemical knowledge.	**0.739**
Factor 3: Mostly Technological Field of Knowledge	**F3**
J: … showed effective technical skills when using technologies in remote teaching.	**0.756**
K: … knew how to solve technical problems related to technology during remote teaching.	**0.747**
L: … proved able to use various internet tools and social media in his classes.	**0.831**
M: … was able to use technology to insert myself into real-world situations.	**0.642**
N: … helped me use technology to gather information, plan and verify my learning.	**0.641**
O: … helped me use technology to build different forms of knowledge representation and work collaboratively.	**0.653**
P: … managed to use computer programs and software created for chemistry in his classes.	**0.715**
Q: … demonstrated knowing how to use technology to research chemistry.	**0.775**
R: … used different technologies to represent chemistry content in their classes.	**0.740**
S: … taught class combining technology, scientific chemistry content and teaching strategies.	**0.732**
T: … with technology, enriched his classes and facilitated my learning in chemistry.	**0.771**
U: … demonstrated technological knowledge, teaching strategies and chemical knowledge.	**0.710**

Based on the data presented in Table 5, the values were measured using the Commonality, which is characterized by the sum of the squared factor loadings of each measured variable and it serves to evaluate the performance of the model: the greater the commonality, the greater the explanatory power of that variable by the factor. The total commonality of the assertions is 11.4797 which, divided among the 21 variables, indicates an average of 0.5466; that is, an average efficiency of around 54.66% of the model in explaining the variation of each variable in the test. Based on the data, it was decided to carry out an analysis of the internal consistency of the factors and possible differences between them, which was measured using Cronbach's alpha coefficient. According to Table 6, it can be seen that the three factors had alpha coefficient values above satisfactory (0.70).

Table 6. Factor analysis from Cronbach's Alpha

Factor	Cronbach's Alpha	Mean	Standard Deviation
F1	0.944	2.639	0.974
F2	0.893	2.762	0.973
F3	0.747	3.598	0.606
Complete questionnaire	0.947	2.811	0.985

To analyze the differences in the mean scores, the non-parametric Kruskal-Wallis test (Kruskal & Wallis, 1952) was used since the mean scores showed non-normal behavior by the Shapiro-Wilk test. Furthermore, Dunn's (1964) post hoc test was used to understand the differences between each pair of factors adopted in the research. The mean scores of the different factors were all significantly different at a significance level of 99%, while statistically significant differences were found between the mean scores of the pairs of Factors 1 and 3 ($p = 0.00$) and 2 and 3 ($p = 0.00$), with no significant difference between Factors 1 and 2 ($p = 0.11$). These results indicate that, globally, Factor 3 has the highest mean score, suggesting that respondents were more likely to agree with assertions related to the area of knowledge specifically linked to science, corresponding to Content Knowledge, thus revealing something quite healthy, when it is thought that mastering the content of the discipline that is taught is a necessary action to be able to develop the teaching process. Factor 2, corresponding to the mostly pedagogical field of knowledge, had the second highest average score, while the first factor, characterized by the field of knowledge that requires technological knowledge, from Technological Knowledge to Pedagogical Technological Knowledge of Content, was in the last position, with a value lower, including the general mean of the instrument.

The average level of agreement per factor is shown in Figure 5, and it is possible to highlight an average percentage of positive self-perception (which encompasses the options "agree" and "strongly agree") decreasing towards Factor 3 (~95%) > Factor 2 (~62%) > Factor 1 (~56%). In this support, based on the data, the differences between the average scores for the different groups are presented in detail in Table 8.

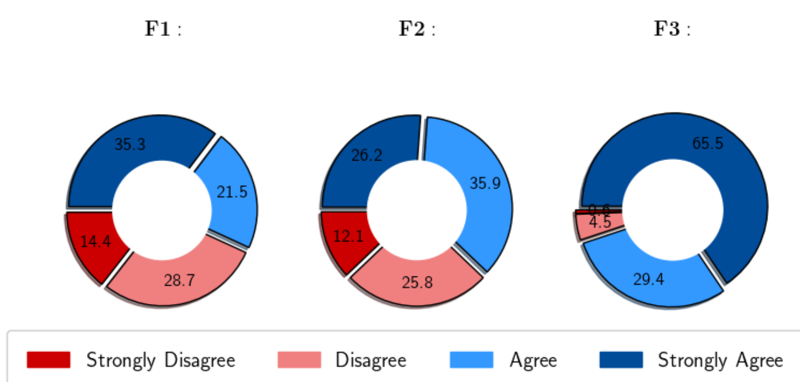


Figure 5. Average agreement by factor

Table 8. Average scores by category

Categorical Variables										
	Gender				**Age**					
	M	**F**		**O**	≤18	**19-24**	**25-30**	**31-36**	**37-42**	**>43**
F1	2.646	2.637		2.528	2.53	2.56	2.56	2.91	2.88	2.80
F2	2.763	2.758		2.944	2.37	2.60	2.64	2.92	2.89	3.01
F3	3.598	3.595		3.777	2.49	2.85	2.92	3.14	3.14	3.30
	Region					**Teacher Education**				
	N	**NE**	**MW**	**SE**	**S**	**LC**	**BC**	**LBC**	**LO**	**BO**
F1	2.36	2.51	2.51	2.63	2.65	2.57	2.53	2.68	2.33	2.70
F2	2.34	2.48	2.60	2.65	2.71	2.55	2.58	2.73	2.59	2.92
F3	2.33	2.52	2.83	2.94	3.01	2.62	2.96	2.93	2.78	3.13
	Graduation Course					**Graduation period**				
	LC	**BC**	**LBC**	**LO**	**BO**	**1-2**	**3-4**	**5-6**	**7-8**	**9-10**
F1	2.54	2.62	2.70	2.72	2.22	2.64	2.51	2.58	2.60	2.74
F2	2.57	2.67	2.74	2.83	2.33	2.56	2.58	2.64	2.76	2.82
F3	2.75	2.91	3.03	3.31	3.00	2.69	2.85	2.91	3.00	3.21

Given the data presented in Table 8, it should be noted that the differences between the mean scores of the instrument were examined using the Kruskall-Wallis test for all categorical variables (Gender, Age, Region, Teacher Training, Undergraduate and Graduation period) since they have more than three "subdivisions".

DISCUSSION

In this field, calling the average score obtained by a certain categorical variable as Level of Agreement, the results attest that, with regard to Factor 3, characterized by the predominantly Technological Field of Knowledge, and with a significance level of 95%, there are no statistically significant differences between the variables: i) Gender and Level of Agreement; ii) Region and Level of Agreement; and iii) Graduation Period and Level of Agreement. Thus, it can be seen that there are statistically significant differences for the variables Age, Course, and Teacher Education (the latter for a significance level of 90%), when compared with the Level of Agreement, indicating that the differences observed in the mean scores of Table 6, for these three categorical variables, are not the result of chance. Thus, for these three variables (which were statistically different), Dunn's post hoc test was carried out, to determine the differences between the Level of Agreement and each of the subdivisions of the three categorical variables mentioned above, taken twice to two. For the Age variable, through Dunn's test, statistically significant differences can be seen between the age groups 19 to 24 years and 31 to 36 years, as well as between 25 to 30 years and 31 to 36 years. For the other two variables (Teacher Training and Undergraduate Course), no significant differences were found between the variables when taken two by two, demonstrating that the scores of the two variables had no direct significant effects on the mostly Technological Field of Knowledge.

In this bias, it is possible to affirm that subjects aged between 31 and 36 years old differ statistically from those with younger age, indicating that Factor 1 exerts a significant influence on the degrees of agreement for subjects in this age group. This design may be a derivation that subjects aged between 31 and 36 are not part of the so-called "digital natives," which means saying that, perhaps, for them there is no transformation in the way the teacher presents or not skills and competences when using technologies in remote teaching, as well as solving or not solving technical problems of a technological nature, among others, using or not using different internet tools and social media during classes. Apparently, these subjects care more about the learning process, which can be related only to scientific and pedagogical activities, than about the specific path during the process. In other words, it is understood that Factor 1, as it presents a predominantly Technological Field of Knowledge, presents a distinction in the degrees of agreement between subjects born in different decades. This corroborates the ideas of Soong and Tan (2010) because, for these students, the teacher must be able to transmit the information known correctly and at the right time; that is, the content of the correct material through the use of good pedagogical activities, regardless of the use of technologies.

Furthermore, it can be inferred that subjects aged between 31 and 36 years are those who are in an advanced period of the undergraduate course, in relation to the others, which means that, regardless of the use of technologies in the pandemic period for pedagogically stimulating learning and the insertion of subjects in the world of chemistry, their teachers were able to demonstrate scientific knowledge in a macroscopic, symbolic, and submicroscopic way. Perhaps this process occurs frequently in the physical laboratories of universities, which characterized the thinking of the subjects in congruence with the teaching actions, even if these did not occur during the pandemic period, thus statistically differentiating the thinking of subjects aged between 31 and 36 years old, who have already experienced face-to-face actions with their teachers, from those aged between 19 and 30, who possibly started their graduation at the beginning of the pandemic.

In line with this, studies conducted by Bedin and Cleophas (2022) reveal that the age group of subjects has a statistically significant influence on the field of technological knowledge, essentially in relation to the skills and competencies of their teachers in the act of teaching. The findings reveal that younger students have different perceptions than older students regarding their teachers' ability to appropriate technology to use software created for chemistry in their classes, and also to build different ways of representing knowledge and working collaboratively. Carlini (2008) justifies this design by stating that teachers have become attached to the process of transmitting knowledge, and the insertion of technological tools in higher education, for example, requires the teacher has a continuous need to adapt in their daily activities, which has hindered the appropriation and use of technologies by teacher educators.

Analyzing Factor 2, fundamentally comprising the predominantly Pedagogical Field of Knowledge, it can be seen that, except for the variable Gender, the other variables showed statistically significant differences when their mean scores were compared. Below, provisional interpretations are given that would need to be tested in future studies, given that, when Dunn's test was applied to each of these categorical variables, it was briefly obtained.

i) **Age:** it was possible to notice that younger people (mainly those still in their teens - up to 18 years old) tend to present a much lower agreement than older students regarding the understanding of the pedagogical actions of teachers being able to make subjects expand their understandings and, among other processes, learn through different biases. This finding may derive from the idea that younger subjects are able, through time and through cognitive and motor skills, to individually expand their learning horizons, managing to deal with their own mistakes and, among other pedagogical actions, to think and learn chemistry in a different multilevel way.

ii) **Region:** statistically significant differences were found between the average scores of the North and Northeast regions when compared to the average scores of the South region, showing a difference in understanding of the teacher's pedagogical skills. This assertion may be linked to issues of infrastructure and didactic conditions, as well as human resources present in the departments of the different universities. After all, historically, in Brazil, the North and Northeast regions face different difficulties with regard to the teaching of chemistry; such as, for example, lack of access to technologies, shortage of qualified teaching workforce, and scientific resources for understanding science chemistry at the macroscopic and submicroscopic levels.

iii) **Teacher Training:** statistically significant differences were observed between the mean scores of students who believe that their teachers have a Licentiate degree in Chemistry with those who think that their teachers have a Licentiate degree and a Bachelor's degree in Chemistry and with those who believe that their teachers have a Bachelor's degree in another area. In addition, distinctions were noticed between the mean scores of students who recognize that their teachers have a Bachelor's degree in Chemistry with those who believe that their masters have a Licentiate and a Bachelor's degree in Chemistry, indicating that teacher training implies the pedagogical actions of the teacher. This investigation is directly related to the scientific-pedagogical action of the teacher, especially because Factor 2 considers the Field of Knowledge mostly Pedagogical. In other words, subjects who believe that their teachers have a Licentiate's degree differ from those who believe that teachers have a Bachelor's degree through didactic action during the pandemic, while the perception of those who tile the training of their teachers as Licentiates and Bachelors derives from a strongly linked pedagogical action to a specific knowledge of scientific knowledge.

iv) **Graduation Course:** statistically significant differences were observed between the average scores of the Licentiate in Chemistry students in relation to the Licentiate and Bachelor of Chemistry students, and of the Licentiate students in another area, indicating that the teacher's pedagogical practice is understood differently depending on the student course. This investigation can demonstrate that the students of Licentiate in Chemistry differ from those of Licentiate and Bachelor of Chemistry because they believe, perhaps, that teaching skills should extrapolate the field of scientific knowledge, looking for an expressive relationship in the pedagogical way of teaching the macroscopic world, symbolic and submicroscopic of chemistry, making it possible to measure agreement in relation to resources, and teaching actions adopted to encourage and guide subjects to think about chemistry.

v) **Graduation Period:** it was possible to find significant differences between the average means of students in the initial semesters (1st to 4th semesters) when compared to the scores obtained from students at the end of the course (8th to 10th semesters). This characteristic can be understood from two distinct but complementary moments. That is, students in the initial semesters may have started their undergraduate courses during the pandemic, which made it impossible for them to evaluate teaching actions of a pedagogical nature in their entirety. On the other hand, this falls on the students of the final semesters, who may have adopted the agreement in relation to the assertions of the Field of Pedagogical Knowledge from the experiences with their teachers before the pandemic, alluding to didactic practices not only in the pandemic.

In summary, regarding the predominantly Pedagogical Field of Knowledge, it is clear that the subjects who are at the beginning of the schooling process in Higher Education, as well as those who are part of a Bachelor's training course, present perceptions and knowledge that are different from those who are at the end of the training course and those who are doing a Licentiate course, essentially on the skills of the teacher to expand the student's thinking through challenging tasks, to guide him to adopt appropriate learning strategies and, among others, to achieve, in different ways, help him to understand chemical knowledge. This finding derives from the conception that final-year students, as well as those who are studying for a Licentiate degree, can have a more acute and grounded consideration of the pedagogical capabilities of their teachers, managing to measure more solid degrees of agreement or disagreement, whether from living with teachers at different times and in different disciplines (Age and Period of the Course) or through in-depth studies on theories that support pedagogical and curricular knowledge (Teacher Training and Course). However, these students are unaware that the quality of teaching does not depend only on the mastery of content knowledge that teachers have since it is necessary to consider fundamental aspects in teaching practice, such as questions about learning styles and assessment (Saraguro, 2020).

Still, in common with the findings in the research of Cleophas and Bedin (2022), it can be stated that the mostly pedagogical field exerts influence on the subjects' conception as to age and period in the course, indicating a failure in the teacher's pedagogical ability in the sense of provoking and monitoring student learning, perhaps by the cultural distance of age or by cognitive maturation due to the time in the course. The research of Silva et al. (2021) adds to this by demonstrating that, depending on the training course, the subjects diverge in relation to elements in the pedagogical field, specifically regarding the ability of the teacher to use different strategies and tools that facilitate learning and stimulate students to collaborate.

Furthermore, in relation to Factor 1, referring to the mostly Scientific Field of Knowledge, it is retained that this was the only one to present statistically significant differences in all categorical variables (Gender, Age, Region, Teacher Training, Course, and Period). We launch provisional interpretations below, however, it is quite pertinent that they can be tested in future studies. Thus, performing Dunn's test, the following conclusions were reached:

i) **Gender:** There were statistically significant differences between men and women, indicating that women tend to agree more with the idea that the professor has demonstrated significant mastery of the scientific knowledge being taught. This finding can reveal beliefs about the source of knowledge, as women can incorporate a very naive perspective (Chen, 2012) in relation to teaching. However, it should be noted that cognitive ability is supported by the concept that individuals operate certain types of information and, therefore, they differ cognitively because they exhibit abilities to a different degree (Marañón, 2014).

ii) **Age:** There was a great distinction between the level of agreement obtained by younger students when compared to more experienced students, in the age group over 37 years. This investigation may be related to the older subjects' ability to concentrate, as well as their experience in relation to the objects of knowledge of chemical science, given the time of studies in the course, facilitating their understanding of the macroscopic, symbolic, and submicroscopic worlds of science, when presented scientifically by the teacher.

iii) **Region:** There were statistically significant differences between the average scores obtained by students from the North and Northeast regions (which showed a lower level of agreement) when compared to those from the Midwest, Southeast and South regions, in addition to differences between the Midwest and South regions, where it was understood that the teacher thought and mastered the chemistry content like an expert. As already mentioned, the North and Northeast regions suffer from a lack of resources in relation to scientific research issues, which can even affect the maturation and updating of the scientific knowledge of professors, since a professor remains in constant improvement. There is no divergence between the South and Southeast regions because it is the Brazilian regions that, geographically, allow a greater relationship of research, allowing professors to have a scientific exchange.

iv) **Teacher Training:** The difference was significant between those students who believe that their teachers have a Licentiate degree in Chemistry when confronted with the average scores of those students who claim that their teachers have a Licentiate degree and a Bachelor's degree or a Bachelor's degree in another area, demonstrating a divergence between the conceptions of that the teacher knows and scientifically masters the chemical science. This characteristic is specific to a group of professors who do research in applied chemistry, notably those that students believe to have a Bachelor's degree, which allows them to have a greater understanding of phenomenology, be it macroscopic, symbolic, or submicroscopic, greater. This effect makes it possible, even during the pandemic, to present sufficient scientific knowledge about chemistry, as well as display a deep understanding of them.

v) **Graduation Course:** Licentiate students in another area showed a higher level of agreement than the others, and this difference was statistically significant, especially in comparison with the level obtained by Licentiate in Chemistry, Bachelor in Chemistry, and Licentiate and Bachelor of

Chemistry students. Therefore, Licentiate students in another area may have a reduced knowledge, when compared to Chemistry, Licentiate, or Bachelor students, in relation to the objects of knowledge of this science, and thus, there is disagreement regarding the agreement in the Field of Knowledge mostly Scientific. That is, a Licentiate in Physics student, for example, when having a chemistry class with a chemistry teacher, regardless of the teacher's level of abstraction, exposure, and thinking in relation to chemical science, will possibly have a perception that the teacher thinks like an expert on the subject since the teacher does not have enough knowledge about chemistry.

vi) **Graduation Period:** It was possible to perceive differences between the level of agreement obtained by students from the first semesters in relation to students from the last semesters, while no dissimilarities were observed between the average scores obtained by students in the middle of the course (3rd to 6th semesters). This finding demonstrates that end-of-course students, because they have scientific knowledge built up over the years, and matured through studies and dialogues, do not expressly agree that their teachers think as experts and have sufficient scientific knowledge about chemistry, unlike students who are starting the graduation process, since they have just arrived from high school and, possibly, their undergraduate professors have sharper scientific knowledge than their former Basic Education teachers.

In summary, when considering the predominantly Scientific Field of Knowledge, it is possible to measure that students in the final periods of graduation, and consequently with more experience (age), have a broader conception and, at the same time, more specific knowledge in relation to the conceptual content, which allows them to agree or disagree more significantly on the actions of: i) the teacher having sufficient scientific knowledge about chemistry; ii) the teacher thought about the scientific contents of chemistry as an expert on the subject; and, iii) the teacher deeply understood the scientific contents of chemistry. Not differently, Licentiate undergraduate students in another area of knowledge, different from Licentiate and Bachelor undergraduate students in Chemistry, agree that their professors master the content of the area and think about it as experts, perhaps because chemistry, being a phenomenological science, presents models and theories that can, over time and from other experiments, be improved, which makes teachers who do not constantly improve themselves feel difficulties in understanding the knowledge of their own area of knowledge.

In corroboration, it is believed that the existence of a significant difference between the subjects of the different regions of Brazil, regarding the perceptions about the competencies and teaching abilities related to the Field of Scientific Knowledge, occurs due to the low concentration of improvement courses in Chemistry for professors from the North and Northeast regions, making them present, in the evaluation of their students, knowledge that is not in-depth in relation to Chemical Science. Finally, it is judged that women, as they show more attention and organization in their studies, especially on exact sciences, agree that their teachers dominate the Chemistry content and think about it as an expert, given that when they have a greater number of connections between nerve cells in the brain, women are able to learn more easily, perhaps understanding that the derivation of this process is due to the scientific abilities and skills of their teachers. However, all provisional interpretations need to be tested in further studies; therefore, future research may also consider replicating this study, collecting information that can deeply investigate the influence of the variables adopted here.

CONCLUSION

The objective of the present investigation was to know the perception that Chemistry higher education students have about their Chemistry teachers in relation to the knowledge proposed in the TPACK model. The results allow us to conclude that, in order to promote more effective instruction by integrating technological, pedagogical, and scientific knowledge with an emphasis on macroscopic, symbolic, and submicroscopic levels, continuing education by Brazilian university professors of

Chemistry becomes necessary, especially related to the mostly Scientific Field of Knowledge (Factor 1), which showed the lowest level of agreement on the part of the interviewees.

Regarding the integration of Johnstone's triangle with the TPACK conceptual structure, it is assumed that the structuring of science under the three aspects of the triangle from the teaching domain of the TPACK structure conjectures the ease of students' cognitive appropriation in the macroscopic, submicroscopic, and symbolic embodied in the objects of chemical knowledge. Therefore, the representational character of chemical knowledge pedagogically based on digital technologies allows students to develop their imagination and create submicroscopic hypotheses and explanatory models based on the analyzed data and macroscopically observed prominences through the symbolic ability to represent specific elements of Chemical Science, using them to build meaningful knowledge.

This study has some limitations. First, the results were based only on a statistical analysis of the data, while more detailed information was not collected. For example, no individual interviews were conducted and no fine-grained analysis of the alignment or misalignment of the survey was carried out according to each participant and the scores assigned to the questionnaire. Thus, to develop a more refined understanding of chemistry students' perceptions of their professors' classes, empirical study, especially qualitative studies, in harmony with quantitative research, is highly necessary.

Second, it was not possible to survey the number of students who received the link to the questionnaire, since the Course Coordinators were contacted and sent the link to the students; therefore, there is no way to measure the research attrition rate. Third, the questionnaire made available to the research participants did not have a section of discursive questions, where qualitative and quantitative data could be crossed, demarcating the results of this study in a mixed way and with a less subjective bias. Fourth, the use of the closed questionnaire in the 21 statements referring to the TPACK is admitted as a limitation of the research, when it could be adapted by inserting statements referring to the context of the subjects, the infrastructure of the institutions, and the teaching beliefs.

Future research should, in addition to improving the proposed model that integrates the Johnstone triangle and the TPACK conceptual framework in teacher education, use elements of the subjects' context, the institutions' infrastructure, teachers' objectives and beliefs (self-efficacy and values), as well as resources, experiences, and knowledge, to make it more specific and comprehensive and consider the inclusion of open questions to elucidate components that guide the development and promotion of teacher training courses regarding the insertion of technologies in a pedagogical way to teach chemistry in its different dimensions.

In addition, given the possibility of adapting and reapplying the questionnaire, it is worth considering the progress of this research in an investigation that centralizes the perceptions of students and teachers about the concept of becoming a technological teacher in different Brazilian contexts, via scientific and didactic appropriation of technology able to outline teaching technological skills manifested after the COVID-19 pandemic in and for pedagogical practice. Still, considering the data constitution vehicle, this research can unfold in studies related to the structure of TPACK in Latin America, in an attempt to help teachers in the appropriation of technologies to link them to viable approaches in teaching chemistry.

Finally, it is necessary to develop a practical training action with a technological bias in the teaching of Chemistry, to play an instrumental role in a student's understanding process. Otherwise, it is necessary to equip undergraduate students and training teachers to be able, in an inter- and intradisciplinary way, to know the objects of knowledge of chemical science in order to improve the pedagogical and technological way of working them together.

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