Research, Society and Development, v. 9, n. 12, e45591211331, 2020
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i12.11331

The concept of acids and bases in the initial training of Chemistry teachers in the perspective of the Theory of Conceptual Fields

O conceito de ácidos e bases na formação inicial de professores de Química na perspectiva da Teoria dos Campos Conceituais

El concepto de ácidos y bases en la formación inicial de profesores de Química desde la perspectiva de la Teoría de los Campos Conceptuales

Received: 12/19/2020 | Reviewed: 12/26/2020 | Accept: 12/28/2020 | Published: 12/28/2020

Kariny Mery Araujo Cunha
ORCID: https://orcid.org/0000-0003-1975-880X
Federal University of Piaui, Brazil
E-mail: karinymery@gmail.com
Inês Maria de Souza Araújo
ORCID: https://orcid.org/0000-0001-8298-7416
Federal University of Piaui, Brazil
E-mail: inesmaria@ufpi.edu.br
Jerino Queiroz Ferreira
ORCID: https://orcid.org/ 0000-0002-9356-8716
Federal University of Piaui, Brazil
E-mail: jerino@ufpi.edu.br
Luciana Nobre de Abreu Ferreira
ORCID: https://orcid.org/0000-0003-3505-9523
Federal University of Piaui, Brazil
E-mail: luciananobre@ufpi.edu.br

Abstract
This paper presents the partial results of research that analyses the aspects of the training of chemistry teachers referred to notions of teaching and learning, based on the Theory of Conceptual Fields by Gerard Vergnaud, which has its focus on the reflective teaching and the conceptual construction. In this stage of the research, it was discussed the results of solving questions about previous knowledge and chemistry problems about acids and bases by students of a teacher training course in chemistry. The discussion was focused on the

perspective of "learn how to teach" based on the knowledge of "learn how to learn", considering that when teachers pose themselves as students, they learn how to learn, which is essential to teach in a significant way. In the students' answers, it was possible to identify different indicators of operational invariant, to which theoretical models were used in the rationale of their justification, representing the scientific formality, however, their explanations ended up reflecting conceptual mistakes that can be acting as epistemological obstacles. This research highlights the relevance of the identification of theorems-in-action to resolve, reflect and discuss the problems of conceptualization in the teaching of acids and bases content, showing that the teacher can contribute with the students' learning, directing them to the expansion and/or modification of theorems-in-action that might act as obstacles in the learning of concepts.
Keywords: Acids and bases; Teaching-learning; Chemistry; Theory of Conceptual Fields; Theorems-in-action.

Resumo

Neste trabalho são apresentados resultados parciais de uma pesquisa que traz a análise de aspectos da formação de professores de química referentes às noções de ensinar e aprender com base na Teoria dos Campos conceituais de Gerard Vergnaud, a qual tem enfoque no professor reflexivo e na construção conceitual. Em tais discussões buscou-se refletir sobre a perspectiva do "aprender a ensinar" com base no conhecimento do "aprender a aprender", considerando que quando professores se posicionam também como aprendizes, eles aprendem como aprendem, o que é primordial para ensinar de forma significativa. Neste recorte da pesquisa, foram discutidos os resultados da resolução de questões sobre conhecimentos prévios e de problemas de química sobre o conteúdo de ácidos e bases por estudantes de licenciatura em química da Universidade Federal do Piauí. Nas respostas dos estudantes, foi possível verificar diferentes indicadores de invariantes operatórios, para os quais foram utilizados modelos teóricos na fundamentação de suas justificativas, representando o formalismo científico, no entanto, suas explicações acabaram refletindo erros conceituais que podem estar atuando como obstáculos epistemológicos. Esta pesquisa ressalta a relevância da identificação de teoremas-em-ação para a elucidação, reflexão e posterior discussão relativas a problemas de conceitualização no ensino do conteúdo de ácidos e bases, mostrando que o professor pode contribuir para a aprendizagem do estudante, direcionando-o à ampliação e/ou modificação de teoremas-em-ação que podem atuar como obstáculos na aprendizagem de conceitos.

Palavras-chave: Ácidos e bases; Ensino-aprendizagem; Química; Teoria dos Campos Conceituais; Teoremas-em-ação.

Resumen

En este trabajo, resultados parciales de una investigación que presenta el análisis de aspectos de la formación de profesores de química en torno a las nociones de enseñanza y aprendizaje a partir de la Teoría de los Campos Conceptuales de Gerard Vergnaud, que se centra en el profesor reflexivo y la construcción conceptual. En dichas discusiones, se buscó reflexionar sobre la perspectiva de "aprender a enseñar" a partir del conocimiento de "aprender a aprender", considerando que cuando los docentes también se posicionan como aprendices, aprenden como aprenden, lo cual es fundamental para enseñar en un significativo. En este extracto de la investigación, se discutieron los resultados de la resolución de preguntas sobre conocimientos previos y problemas de química sobre el contenido de ácidos y bases por parte de estudiantes de pregrado en química de la Universidad Federal de Piauí. En las respuestas de los estudiantes fue posible verificar diferentes indicadores de invariantes operativos, para lo cual se utilizaron modelos teóricos en la justificación de sus justificaciones, representando el formalismo científico, sin embargo, sus explicaciones terminaron reflejando errores conceptuales que pueden estar actuando como obstáculos epistemológicos. Esta investigación destaca la relevancia de la identificación de teoremas-en-acción para la elucidación, reflexión y discusión posterior relacionada con problemas de conceptualización en la enseñanza del contenido de ácidos y bases, mostrando que el docente puede contribuir al aprendizaje del alumno, dirigiéndolo a la expansión y / o modificación de teoremas en acción que pueden actuar como obstáculos en el aprendizaje de conceptos.

Palabras clave: Ácidos y bases; Enseñanza-aprendizaje; Química; Teoría de Campos Conceptuales; Teoremas-en-acción.

1. Introduction

In the last years, researches in the area of education in sciences have been carried out about the pedagogical motto "learning how to learn", that is, about cognitive systems related to the processes of teaching and learning. According to Tauceda and Del Pino (2014, p. 256), "the teaching and the learning are deeply related", supporting the affirmation by Vergnaud, Rogalski, and Artique (1989) that, for the teacher to teach, he/she must know in what ways the student understands certain subject, on other words, the teacher must acknowledge "what,

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how, when and why" to teach certain subjects (Magina, 2005, p.1). This way, the teaching and the learning are part of the same pedagogical universe (Tauceda, & Del Pino, 2014), which must be considered mutually so that the educational process can be favored.

The social context provides to the teacher the development of the learning how to learn, through problematizing situations that enable him/her to raise a series of questions about the teaching practices (Tauceda, 2014). Schön (1992) points out that it is before it that the teacher develops his/her formation.

In this scenario, the teacher starts to analyze his/her competences and function as a mediator of knowledge; then, it is through his/her formation that, besides obtaining new knowledge, he/she must be able to articulate them to propose solutions to the difficulties that may appear (Fernandes, & D'Avila, 2016).

In this sense, the Theory of Conceptual Fields (TCF) is an important referential for focusing on the educational practice, in which the teacher, through the reflexive-action, can consider his/her limitations and, if necessary, reorder his/her knowledge to improve the performance of his/her teaching actions, because, based on this theory, the teaching is centered in the student, and the teacher not only teaches but also acts as a mediator who is responsible for developing dialogical situations in which the students might expose their previous knowledge, which will guide his/her practice (Vergnaud, 2013a).

In this context, the teacher acts as a mediator promoting different situations, so the students may apply the studied concepts and recognize their advancements and reversals in the teaching, because, in this process, it is possible to infer the operational invariant (concepts-in-action and the theorems-in-action), that constitute the part of the knowledge of the individual during the resolution of situations to verify the level of appropriation of certain conceptual field (Vergnaud, 2009).

The introduction of the students to situations, as the explanation of its "cognitive content", enables the analysis of its progress inside of a conceptual field, besides identifying difficulties and inferring implicit operational invariants that may appear as obstacles to the conceptual learning, preventing this progress (Grings, Caballero, & Moreira, 2008). This way, the explanation of the meanings assigned to existent concepts in a certain conceptual field allows us to verify operational invariants scientifically correct or not. In this segment, the already existent knowledge is essential to cognitive development. As it is pointed by Ausubel (cited by Moreira, 2012, p.46), "the most important factor that influences in the learning is what the student already knows". This way, explaining the knowledge that the student has and verifying the difficulties that are presented in the previous knowledge is favorable to the development of the student in a conceptual field.

Broadly, the focus of the TCF is to explore the development and the learning of complex competences of the students, helping the teacher to comprehend the teaching processes and practices, which provide the development of learning (Santana, Alves, & Nunes, 2015; Vergnaud, 1990).

Therefore, with this study, we aim to verify, based on the Theory of Conceptual Fields by Gerard Vergnaud, the possible indicators of operational invariants (theorems-in-action) present in the answers of undergraduate students of chemistry to questions of previous knowledge and problems about acids and bases, to investigate the influence of this knowledge in the development of the conceptualization of the involved ones, that is, in the process of “learning how to learn”. It is assumed from the hypothesis that stimulating this process favors discussion from the perspective of the “learning how to teach”, considering that when teachers pose themselves as learners, they learn how to learn, which is essential to teach in a significant way.

2. Theory of Conceptual Fields

The Theory of Conceptual Fields (TCF) is a cognitivist theory, neo-piagetian, which focus on the studies of the conceptualization of the real, that is the core of the cognitive development and the learning of complex competencies, depending on the resolution of situations related to the content present in a “field of concepts” distinct from one another, however, correlated, searching to understand the filiations and ruptures in the formation of knowledge (Moreira, 2002, 2009; Vergnaud, 2013b, 2017a).

Vergnaud explains that the more an individual is confronted with situations (and more complex), the more he/she develops and becomes able to master such concepts (Fanaro, Otero, & Moreira, 2009). For this reason, Moreira (2009, p. 37) explains that the focus of Vergnaud’s theory is on the study of the general logical operation and the general structures of the thinking for the study of cogintive functioning of the “subject-in-situation”.

He starts from the principle that the knowledge is organized in conceptual fields, which, for the subject to obtain his/her mastery, takes time and happens through experiences, maturity, and learning (Vergnaud, 1989). Thus, a conceptual field is made of different concepts “socially defined and that are applied in different events by an individual” (Cedran, & Kiouranis, 2019, p.65) since a concept by itself does not have meaning, it is through these situations to solve that it acquires meaning.

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Hence, it is understood by concept a "distinct triple group" of elements, though dependent, that would be: S, group of situations that make the concept meaningful; I, group of operational invariants that establish the concept, structure the ways of organizing the thinking and will be raised in the situations; and L, group of linguistic and symbolic representations that are used to portrait the concept, its priorities and the situations to which they are related (Moreira, 2002).

The relation among the components of this group is established by the implication that the invariants depend on the situations, and the group of schemes used by the subject in that situation, that is, the three must be studied simultaneously and "one concept alone does not refer to only one type of situation and only one situation cannot be analyzed with only one concept" (Moreira, 2002, p.10).

From the perspective of the TCF, it is on the schemes that the knowledge-in-action of the student is contained, that is, the cognitive elements makes the action of the student operational. A scheme contains operational invariants (concepts-in-action and theorems-in-action); goals and anticipations (probable purposes and direction of the action); rules of action (they allow the creation of a group of actions); inferences or reasoning (possibility to consider the situation based on the other components of the scheme) (Rocha, & Basso, 2017; Vergnaud, 2013b).

Among the mentioned elements, only the operational invariants are called "indispensable" on the association between the theory and the practice, that is, the relation between the knowledge-in-action and the situation in which the student was submitted (Greca, & Moreira, 2002; Vergnaud, 1998). According to Vergnaud (1982), a theorem-in-action is a proposition that is supposed to be truth by the individual, which might be scientifically correct or wrong. A concept-in-action is an object, a predicate, or a category of thinking considered relevant or not. In that respect, there is a dialectic relation between concepts and theorems-in-action, since the concepts are contained in the theorems and the theorems are hypotheses that assign contents to the concepts (Greca, & Moreira, 2002). For example, although it is known the concepts-in-action pressure, volume, and temperature, considering the existent relation "between the increase of pressure, when the volume of a container is reduced, with constant temperature" depends on a theorem-in-action (Cedran, & Kiouranis, 2019, p.74).

It is worthy to mention that in the previous conceptions of the students there are concepts and theorems-in-action, which are not considered true theorems and scientific concepts, however, they can become it through the explanation promoted by the action of the teacher when providing means for such conceptions to be in addition to explained, negotiated and transformed in scientific concept (Antonello, Garcia, Santarosa, Baggio, & Lopes 2018). Thus, the previous knowledge of the students must not be ignored in the processes of teaching and learning, since they are considered by Ausubel "as the most important isolated factor in the determination of the teaching process" (Alegro, 2008, p.15).

Starting from this assumption, many of the students' difficulties on the acquisition of scientific knowledge might be associated to these knowledges-in-action that, for being implicit and not have been encouraged to explicit them, ended up becoming obstacles to the obtaining of scientific concepts (Parisoto, Moreira, & Moro, 2013). Krey (2009) highlights that both the operational invariants and the schemes, usually are used by individuals unconsciously, because of that, it is the teacher's responsibility to mediate and provide means to the explanation of this knowledge.

In a literature review done in periodical and events, national and international, in the field of science teaching, during the period from 2008 to 2018, it was possible to find 66 articles dealing with this theme, of which only eight were related to the teaching of chemistry (Cunha, & Ferreira, 2020). It is possible to consider this a scarce amount as compared with other areas of science, considering the relevance of the implementation of methods based on the construction of concepts with the TCF proposal, what can significantly contribute to the processes of teaching and learning of this area of the natural sciences, which demands the usage of the abstract reasoning by the students, what makes its comprehension more difficult (Santos, 2009).

The search points, yet, to a tendency of the theme in the higher education, due to its contributions to the cognitive development of learning complex competences of the students and the search for comprehension of the filiations and ruptures in the formation of indispensable knowledge especially to this level of teaching (Moreira, 2002, 2009; Santana, Alves, & Nunes, 2015; Vergnaud, 2017a).

3. Methodological Procedures

This paper is about a part of broader research developed by the authors, which is presented as a qualitative investigation, for having as characteristic the possibility of being applied to different researches, considering that each one "implies specific methods to evaluate the possibility of its realization, as well as the procedures to be adopted" (Bogdan, & Biklen, 1999, p.90).

The research had as its focus to promote activities to chemistry teachers in initial training, based on the reflexive formation and the cognitive and constructivist basis of the Theory of Conceptual Fields. For so, weekly meetings were organized with Chemistry university students enrolled in the subjects of Supervised Practice III and IV at the Federal University of Piauí throughout the 2019 academic year, in which 8 students participated. The project for this research was approved by the Ethics and Research Committee of the Federal University of Piauí, registered on Plataforma Brasil, under the identification CAAE: 11341219.7.0000.5214.

In the first semester of applying the proposal, a questionnaire was given to collect the students' previous knowledge around the concepts of bases and acids. After this stage, two problem-situations were presented involving the same concepts, for which we asked the students the results written.

Subsequently, in the second semester, the university students were subjected to a process of formation based on the TCF where contents related to the teaching practice were presented focusing on the pedagogical motto "learning how to learn", aiming to promote the reflexive formation, centered on the building of the individual's knowledge. It is important to emphasize that during this period the answers given by the students related to their previous knowledge and to the opted procedures to solve the problems were discussed and related to the aspects of the TCF, as concepts and theorems-in-action and the effects in the teaching practice.

In this manuscript, it is presented the analysis and discussion of the data referent to the previous knowledge of the students that were collected on the questionnaire created with this purpose (especially the two first questions) and the results presented by them to the proposed problems. The content of acids and bases involves a range of concepts and interconnected fundaments, which imply, through their comprehension, in the mastery of this content. Bearing this in mind, the results were evaluated through the TCF in the identification of the conceptions and the processes of conceptualization of university students when facing problematic situations approaching the subject. It is important to highlight that the solutions occurred individually and with access to material for consulting. Fictional names were given to the students, to protect their identity and their answers were transcribed as they were on the questionnaire.

4. Results and Discussion

Based on the principles of TCF, we started from the hypothesis that confronting the students with different situations involving the same conceptual field and seeking to recognize signs of operational invariants might make its learning more likely to the construction of concepts in a significative way.

When seeking to explain the knowledge contained in the operational invariants, the student provides the following and analysis of his/her learning for the teacher, besides having the opportunity to make a self-evaluation about it, as well as recognize some gaps and mistakes present in it, which allows later adequacy to what is accepted in scientific terms.

Through the explanation of the knowledge, it is possible to identify possible signs of operational invariants – possible signs because the identification of operational invariants demands more time and a bigger variation of situations (Raupp, Serrano, & Moreira, 2009) – contained in the answers of the students, allowing to verify its compliance with the scientific knowledge.

For this purpose, initially, it will be presented the discussions related to the answers for the two first questions present on the questionnaire of previous knowledge, related to their understanding of acids and bases and, later, it will be explained the answers given to the two proposed problems about the same subject, both analyzed according to the TCF, focusing especially in the possible indicators of operational invariants.

From the answers of the students, different categories were created to characterize these answers, as well as to organize the discussion, which are shown in Chart 1.

Chart 1 – Categories elaborated from the answers of the undergraduate students for questions 1 and 2 of the questionnaire about previous knowledges and problems 1 and 2, both about acids and bases.

<table>
<tr><th colspan="4">CATEGORIES</th></tr>
<tr><th>Question 1</th><th>Question 2</th><th>Problem 1</th><th>Problem 2</th></tr>
<tr><td>Theories</td><td>Hydroxyl</td><td>Water and base</td><td>Transformation of methylamine</td></tr>
<tr><td>Hydrogen/proton</td><td>pH</td><td>Neutralization</td><td>Acid adhesion to methylamine</td></tr>
<tr><td>pH</td><td>Neutralization</td><td rowspan="2">Not answered</td><td rowspan="2">Neutralization</td></tr>
<tr><td>Corrosion</td><td>Theories</td></tr>
</table>

Source: Authors (2019).

As noted in Chart 1, categories were elaborated based on the content of the answers given by the graduates to the questions and problems, which was based on the exposition of the theories that support the content, as well as on the description of the characteristics and processes involved in the reactions between species with acidic and basic behavior.

Besides that, it was discussed the possible indicators of theorems-in-action identified on the answers and their reflexes on the explanations of the students. The possible indicators of theorems-in-action here identified are about the way the students used the concept to fundament their answers (Grings, Caballero, & Moreira, 2008).

4. 1 Previous Knowledge

Question 1: What do you understand by acid?

The content of acids and bases is approached according to three main definitions in the classroom and in manual and textbooks, which are originated from the theoretical models by Arrhenius, Brønsted-Lowry e Lewis. Thus, some answers were framed in the category Theory, which refers to the usage of these theories by the students to fundament their explanations:

> *According to Arrehenius, acid is a substance that releases* H^+ *in a solution. Now, according to Brønsted-Lowry a substance is acid when it is proton donor. According to Lewis, acids are a substance that are electron receiver. The theory of Brønsted-Lowry encompasses the theory of Arrehenius and the definition of Lewis encompasses both. Thus, the definition of Lewis is considered the most complete* (Cláudio).

In the answers, it was possible to identify three types of possible indicators of theorems-in-action: "*releases* H^+ *in aqueous medium*", "*proton donor*" and "*electron receiver*", which denotes that the student presents his conception of acid and base grounded on the three theories. It is highlighted that the student Cláudio was the only one to use more than one definition to fundament his answer. However, this answer reveal concepts that are very close to those presented in textbooks and in the teachers' speech, not being unusual to happen in different levels of teaching (Figueira, 2010). It is also noticed that the student emphasized more the description rather than, in fact, the explanation of his perception about acids, providing a suggestive information that the student seems to have memorized arbitrarily the definitions, which enables the occurrence of different mistakes, since the automatization of concepts must be conscious, because, if it is the opposite, they can become meaningless (Kikuchi, 2012).

Besides that, the possible indicator of theorem-in-action "*releases* H^+ *in aqueous medium*", referent to the theoretical model of Arrhenius, reveals, similarly to the obtained by Silva et al. (2014) the use of the verb "to release" to explain the concept of acid, since such conception points to an erroneous comprehension that could lead the students to believe that if there is the releasing of H^+ it is because the species in question has in its formula the hydrogen, fact that not always happen, because, thus, different substances could not be categorized as acids by this definitions, as, for example, the $Al_2(SO_4)_3$ (Lima, & Moradillo, 2019).

This answer shows the using of a possible operational invariant by the student, that probably is acting as an subtancialist epistemological obstacle, which usually is manifested in the learning of chemistry and presents itself as an attribution "to the substances diverse qualities, both the superficial quality and the deep quality" and difficulties the learning and the reasoning of new knowledges (Silva et al., 2014, p. 263).

This possible indicator of theorem-in-action was also approached in other answers, belonging to the category *Hydrogen/proton*, represented in the answer of the student Débora that "*acid are all substances the in the aqueous medium releases* H^+". Such perceptions appear to be limited in relation to the acid-base behavior, have rooted in them previous conceptions that the students acquire during high school and, if not discussed and clarified, may make it more difficult the learning of conceptual contents during the higher education and reflect during the teaching practice. The comprehension of the conceptual field of acids and bases is full of previous conceptions (Alvarado, Garritz, Cañada, & Mellado, 2015) acquired, usually, during the school years, which are considered by Vergnaud as "precursors" of the new knowledges to be obtained. From this, it is born this the necessity of the teacher to identify the theorems and concepts-in-action, which are not real theorems and scientific actions, but may evolve into them, although it is admitted that there is a big gap between them, what reinforces the relevance of the teacher's role in treating these knowledges. For the author, in the previous knowledges are contained the knowledges in action, usually implicit, that may evolve along the educational process and become explicit scientific knowledges (Grings, Caballero, & Moreira, 2008).

In addition to that, this conception, many times prevenient from chemistry textbooks, that hydrogen must be component of the substance that increases the concentration of H^+, cause conflicts, because it leads the students to believe that the increasing of the acid character is related to that and not to the ionization constants (Ka) of these compounds, as it is the case of the H_3PO_4 and HCl (Silva, & Amaral, 2014). On other words, although the H_3PO_4 presents in its composition three hydrogen acids, it is an acid weaker than HCl, because of the different ionization constants of these compounds (Boz, 2009). It signs the necessity of working, on the initial formation, situations that help the teachers in the construction of scientific concepts, who will be responsible for teaching their students.

The expression "*Present concentrations of* H^+" was another possible indicator of theorem-in-action identified in this category, referent to the answer of the student Raquel: "*Substance that presents concentation of* $[H^+]$". It is noticed that the student present an incomplete answer in relation to the Arrhenius theory, although she mentions the proton (H^+), because she ignores the aqueous medium, suggesting a wrong explanation about the concept, since the theory is fundamented in the explanation of acids and bases phenomena in aqueous systems (Souza, & Silva, 2018). This fragment demosntrates that the indicator of possible theorem-in-action can be presented as an epistemological obstacle in relation to the transition of precursor concepts to new concepts. Thus, such conceptions can lead to mistakes, if they are not submitted, in this case, to the mediator action of the teacher, which is essential, since the teacher is responsible for promoting problematizing situations for such conceptions to be evidenced and circumvented when necessary (Vergnaud, 2017b).

In another answer from the same category, the student José makes it implied the idea of "*proton releasing*", using the hydronium ion to represent one of the products of the described process:

> *Chemical substances that in an aqueous state suffer the process of ionic dissociation, where one of these ions would be the* H_3O^+ *responsible for the acidity of the substance in question. Such substances have a pH under 7* (José).

In this answer, the student also uses the theory of electrolytic dissociation of Arrhenius, seeking to explain acid and bases characteristics resulting from the behavior of hydrogen and hydroxide ions in aqueous systems, that is, the reaction between the chemical species and the water (Souza, & Silva, 2018). However, when referring to the process of ion formation, he defines it as an "ionic dissociation", being the process of ionization in acids what happens. Such a mistake can be the result of the lack of explanation of these conceptions, which may be acting as an obstacle in the comprehension of the involved aspect both in the process of dissociation and ionization.

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As it is described by Silva, Eichler, Salgado, and Del Pino, (2008), in different teaching materials, it is used the term "dissociation" and "ionization" as synonyms to explain acids and/or bases reactions in an aqueous medium. The authors quote different works where such observations were made, for example, the work of Mahan (1995), in which the author explains that the strength of the acids is connected to its level of dissociation, indicating that the higher the level, the stronger the acid will be (Silva et al., 2008).

About this question, Schultz (1997, p. 898) points that "the terms ionization and constant of ionization must be used exclusively in the contexts where the ions are formed from not ionic species" and "the term dissociation must be used only in the context of species separating their components". Before that, the usage of the term "ionization" would be more suitable for the explanation of the formation of ions in the question. The student also tried to assign a factor for the acidity of the substance, pointing out the hydronium ion as responsible for this characteristic.

Arrhenius (1903) proposed the theory of electrolytic dissociation and considered that the water suffers the process of auto-ionization described by the equation $H_2O \leftrightarrows H^+ + OH^-$. In this balance, it is verified the relation proposed by the constant of water, $K_w = 1{,}0 \times 10^{-14} = [H^+][OH^-]$, where $[H^+]=[OH^-]= 1{,}0 \times 10^{-7}$ mol/L, so, in pure water, pH= pOH= 7 (Silva, Nascimento, Cunha, & Bueno Filho, 2018). Thus, the concentrations of H^+ and OH^- produced through this process do not attribute acid character nor basic character to the medium. However, when you add a substance that increases the concentration of these ions, the medium will become acid if there is an increase of the concentration of H^+ and basic if there is an increase of the concentration of OH^-.

As emphasized by Vergnaud, the domain in a conceptual field occurs gradually, which may be favored by exposing the student to different situations that approach the conceptual field to be worked, and about which they may consider if their conceptual conceptions are enough to solve them. The content of acids and bases is considered one of the "densest" topics of the chemistry curriculum, since its comprehension is based on the understanding of distinct concepts, such as the kinetic theory, nature and composition of the solutions, atomic structure, ionization, covalent bond, symbols, formulas and equations, the theory of balance, among others (Sheppard, 2006). In this answer, the student presented some difficulty in one of the components of the concept field, which may influence the effective learning of this content, reinforcing what was already mentioned.

The pH was also identified in the answers of the category with this name, in the indicators of theorems-in-action "*present acidity from 0 to 7*" and "*substance with pH that goes from 0 to 6*":

> *They are chemical substances that present acidity from 0 to 7 in the pH scale, depending on the subject or researcher, acid is a substance that gives electrons or is a substance that receives electrons* (Paulo).
>
> *Acids are substances with pH that goes from 0 to 6, with the possibility of being a substance that in contact with any object may cause corrosion* (Pedro).

In the possible theorem-in-action indicators of these responses, it is verified a conceptual mistake indicating that it is not clear for the students that the values of pH below 7 represent substances of acid character. The affirmation "*presents acidity from 0 to 7*" includes the value seven as an acid medium, and the affirmation "*substances with pH that go from 0 to 6*" ignores the values between 6 and 7. If this was true, the substances with pH 6,5 would not be classified as acids.

In the category *Corrosion* it was included the answer that relates the corrosive power of the acids, which presents the possible indicator of theorem-in-action "*they are corrosive, burn the skin*":

> *Acid – hydrochloric acid – are substances that in aqueous solution release H^+ they are corrosive, burn the skin, they are very dangerous* (Maria).

The possible indicator of theorem-in-action observed in this answer is based on the conception of a phenomenon associated with the senses, "*burn the skin*". Silva and Amaral (2014) identified on their paper that the properties of the substances are important because they allow identifying the acids from their organoleptic properties, as the taste and damages that they can cause in material and/or skin. However, such conceptions may create wrong conceptions, as observed in the research of Domíngues-Amaya (2019), where the students described that substances with acid behavior cannot be included in the human diet. Such indicator, then, refers to the idea that the knowledge was built from the common sense and this knowledge, when not confronted, explained or even criticized, may end up in the existence of obstacles that will complicate the constitution of the scientific knowledge (Silva et al., 2014).

Furthermore, it is worthy to mention that the process of didactic transposition represents an essential role in the process of teaching-learning, for it is through its meaning that the scientific notions (academic knowledge) become more accessible for the students, that is, are transformed "from a knowing of reference that is, in general, the knowledge of the specialists from the subject (the knowing wise)" (Almouloud, 2011, p. 191).

However, it is in this process that different conceptual problems can originate. For so, the teacher must pay attention to the probable existent mistakes in most manuals, which may be full of conceptions of their authors, generating distinct modes of approaching the subject, which is likely to have incoherences, including excessive simplifications made, many times, trying to make them closer to the possible audience (Souza, Santana, Silva, Silva, & Simões Neto, 2016). Then, the teacher must recognize the relevance of the explanation of the contents included in the manual, which is the result of the modification of the knowing accomplished by the didactic transposition.

Schuhmacher, Alves Filho, and Schuhmacher (2017) explain that based in Brousseau, certain epistemological obstacle results in knowledge gained in a wrong way, loaded of incoherent principles. Besides the epistemological, Brousseau highlights the existence of possible didactic obstacles, suitable to complement this discussion, that have their origin in the excess of simplification or restrictions of concepts (abstracts or complexes) made trying to approximate them to the students (Figueira, 2010).

Question 2: What do you understand as base?

In the category *Hydroxyl*, it was grouped the answers where the students correlate the bases to the hydroxyl (OH^-), as it is illustrated on the following examples:

> *Alkaline substances constituted by the ion OH^- (hydroxide), and have a pH above 7. Such substances, depending on their origin, may be more or less basic and/or irritating (José).*
>
> *Substances that in the aqueous medium release OH^-, a basic concept, but that helps the understanding very much (João).*

On these answers, it is clear the following indicators of theorems-in-action: "*presents the concentration of [OH^-]*", "*constituted by the ion OH^-*", *"have pH above 7*" and "*in the aqueous medium releases OH^-*". These indicators of theorems-in-action reflect that the identified constitutional aspects end up starting to be attributed to the behavioral (Liso, & Torres, 2002).

The indicator "*in the aqueous medium releases* OH^-" refers to the superficial approximation to the theoretical model of Arrhenius for bases, since the student refers to the aqueous solution in his answer, as verified in other descriptions, whose model was more approached in the attempts of explanation. It is noticed that the term "release" was also used, as discussed before, which may represent an obstacle for the comprehension of the content, leading them to believe that only substances with OH^- can be classified as having basic behavior. Such conception also may be inferred in the indicator of theorem-in-action "*constituted by the ion* OH^-".

The category *pH* brings answers where the students classify the bases according to the pH scale:

> *They are substances with a pH that varies from 8 to 14* (Pedro).
>
> *Base is a substance in the scale from 7 to 14, they are substances that may also hurt the skin like acids, they are elements that receive or give electrons* (Paulo).

It is noticeable the presence of two indicators of theorems-in-action with the same explanation intention, however, with distinct points of view: "*substances with a pH that varies from 8 to 14*" and "*substance in the scale from 7 to 14*". About the last one, it was possible to notice other indicators: "*substances that may also hurt the skin like acids*" and "*they are elements that receive or give electrons*". Such indicators point to the same conceptual mistake trying to explain the concept of acid from the pH scale, restricting the classification of the substances as acids. In these answers, the student Pedro did not include values above seven for the basic substances, and the student Paulo attributed the value seven, which is the reference of neutral pH.

It is verified, yet, that the pH scale was used on both answers, however, the students did not present a proper explanation to the question, which possibly may be related to the arbitrary memorization, without the correct interpretation (Silva et al., 2008). Besides that, there is also a confusion between the definitions of Brønsted-Lowry and Lewis, when it is triggered the indicator of operational invariant "*receive or give electrons*", that is, on the definition of Brønsted-Lowry, a substance has basic behavior when it receives protons and, on Lewis's definition, when it gives pairs of electrons.

Gama and Afonso (2007) demonstrated in their work that the pH scale was proposed initially by Hans Friedenthal in 1904, who proposed the using of the concentration of the hydrogen ion to characterize solutions, indicating that the alkaline solutions could be characterized as the concentration of the hydrogen ion, as long as they were equivalent to 1,0 x $10^{-14}/C_{H+}$, on other words, $[H^+]$ x $[OH^-] = 10^{-14}$ being later studied by Sören P. T. Sören P. T. Sörensen, in 1909, who suggested that the acidity could be expressed using the negative logarithm of the concentration of hydrogen ion: pH= -log$[H^+]$, in which the concept of pH is related to the aqueous and diluted solutions. This way, these complementary studies enabled the possibility of calculating the basicity of a medium (pOH) through the expression. pH + pOH= 14, pointing out the relevance of the ionic product of the water (K_w) for the determination of the pH. In this sense, it is noticed that the established values of the pH scale "are not arbitrary", but they have their origin in the experimental value of K_w (Gama, & Afonso, 2007, p. 233).

Thus, the use of situations with the same content, varying only their levels of complexity helps with the reiteration of their concept and signification in different contexts. However, if the presented situations have the same rigor, the student's learning may become restricted, what shows, once again, how essential the teacher's role is on the proposition of problems that involve different aspects of the content for its better comprehension (Hilger, & Oliveira, 2012).

The category *Neutralization* brings the answer that mentions this phenomenon in its explanation:

> *Base – sodium hydroxide (NaOH) – they are substances that in aqueous solution release OH^-, neutralize the acid. $NaOH \rightarrow Na^+ + OH^-$* (Maria).

In this answer, it was possible to verify the possible indicators of theorems-in-action: "*substances that in aqueous solution release OH^-*" and "*neutralize the acid*", besides the symbolic representation that was not explored in other students' answers. However, it does not represent the state of the substance in question and much less of the formed ions, that is, although it is evidenced the approximation of her conception to the Arrhenius theory, it does not present enough elements to support the answer. It is noticed, again, the use of the verb "release" that, as mentioned, indicates a substantialist obstacle.

The category *Theories* brings the answer based on the theories of the definition of acids and bases:

> *According to Arrhenius, a base is a substance that releases OH^-. According to Brønsted-Lowry, a base is a substance that receives the proton. According to Lewis, a substance is basic when it gives electrons. The Brønsted-Lowry Theory encompasses the Arrhenius theory and the definition of Lewis encompasses both. Thus, the definition of Lewis is considered the most complete* (Cláudio).

Similar to the previous questions, the student uses the indicators of theorems-in-action "*substance that releases OH^-*"; "*base is a substance that receives electrons*", bringing a conception based on the definitions proposed by three theories. This excerpt is an example that points out what is discussed in the academy when this content in terms of "functions" is worked – suggesting the memorization of rules and classifications –, which several times move the students away from the complete comprehension of the relativity of the compounds.

The category *Receive H^+* was represented by Debora's answer when she considered "*Base all the substances that in the aqueous medium receives H^+*". In this answer, there is the presence of the possible indicator of the theorem-in-action: "*all substances that in the aqueous medium receive H^+*". In this theorem-in-action, it is identified a mix of the theoretical models of Arrhenius (*aqueous medium*) and Brønsted-Lowry, (*receives H^+*). As seen in other studies, the students tend to confuse the theories, since they are presented by the teacher several times without the proper comparisons and complementarities generating, this way, a mixture of information without significations (Carr, 1984).

Arrhenius's definition is presented, traditionally, as an introductory concept to the content of acids and bases, and is one of the biggest generators of learning obstacles of these concepts (Hilger, & Oliveira, 2012), because it is presented wrongly, both for the teachers and textbooks (Silva et al., 2014), although it is recognized that the presentation of the theory in such way allows the comprehension in a simpler and appliable way, in many cases (Souza, & Silva, 2018). These conceptual misconceptions may originate from the approach of the three theories almost simultaneously, incurring the use of one definition to explain others. Silva and Santiago (2012, p.78) explain that the "adoption of the acid-base concepts of Arrhenius is justified by the historical importance of the theory and, mostly, by its broad applicability in aqueous systems". However, it is the teacher's responsibility to present the concepts according to more extensive theories, as it is the Brønsted-Lowry theory.

As observed by Nascimento and Santos (2019), the explanations regarding the conceptions about bases are less extensive in comparison to the ones about acids. The reason for this fact may be explained by a bigger identification and presence of the acids in the daily language than the bases. It is also emphasized that, as in the acids' description, since such behavior is correspondent to the other species where the interaction occurs (Campos, & Silva, 1999). Even if they mention the solvent involved in the definition, they do not refer to a possible interaction between them, without a discussion about the properties as the result of the interaction between substances.

Therefore, acids and bases must be taught in terms of behavior, that is, the result of reactions, and not only as an inorganic function, as it is commonly presented to the students (Silva et al., 2018). Studies have shown that this content is commonly approached in terms of the sequence of the theoretical models of Arrhenius, Brønsted-Lowry, and Lewis, respectively (Kiouranis et al., 2005).

For recognizing the gaps left by the use of such sequence, Paik (2015) proposes a new connection among the definitions, founded on the ontological categories of the scientific concepts, from the approaches of matter and process. For the author, there are differences among the ontological categories of the scientific concepts and they must be considered, bearing in mind that many times they make it impossible to change the ontological category of certain content to the other. As it is explained by Souza and Silva (2018), the chemistry has as its focus the study of the matter and the reaction, as it is observed in the definition of Arrhenius, which suggest acids and bases as something material, while in Brønsted-Lowry's definition, they are a process, approach the reaction that occurs among substances. In the same way, the definition by Lewis is related to the chemical reaction, but more broadly, because it includes reactions that do not include protons (H^+). This way, the theoretical models of Arrhenius and Brønsted-Lowry/Lewis must be considered in terms of distinct ontological categories, generating bigger conditions for a more significative comprehension of the content (Kiouranis et al., 2005).

4.2 Resolution of problems

In this section, it will be presented the resolution of the students to the proposed problems related to acids and bases. For this purpose, the answers were transcribed and organized into categories of explanation. In problem number 1, it was given a situation where the students needed to sign the substance that would better lessen the effect of the sulphurous acid spilling on the ground, justifying the answer, among the following options: diesel oil, H_2O, $Ca(OH)_2$, HNO_3 and NaCl.

From the eight students that answered the problems, seven of them chose the Calcium Hydroxide – $Ca(OH)_2$. This way, based on the justifications that were presented for the solution of the problem, three categories were elaborated: *Water and base,* answers that were signed the option H_2O and $Ca(OH)_2$; *Neutralization,* answers justified around the process of neutralization; and *Did not answer*, created to put the answer of a student that did not justify the option signed.

On the category *Water and Base*, the undergraduate students presented justifications based on the using of water and base to lessen the effects of the acid:

> *Depending on the amount of spilled acid, we can reduce its concentration with H_2O diluting it, but more effectively, we can use $Ca(OH)_2$, a strong base of calcium eliminating the acidity of the acid (Paulo).*

> *I would use H_2O and $Ca(OH)_2$, with these two chemical substances, I would prepare a solution strong enough, because the calcium hydroxide $Ca(OH)_2$ is a base. And I would apply to the place where there was the leaking of sulphurous acid, but with caution to not put the $Ca(OH)_2$ solution in excess. And when the basic solution was applied there would be the reaction of neutralization* (Raquel).

In these answers, it was identified the following possible indicators of theorems-in-action: "*it is possible to reduce the concentration of the acid with the addition of water*"; "*the $Ca(OH)_2$ eliminates the acidity of the acid"; "H_2O and $Ca(OH)_2$ form a very strong solution*" and "*when adding the basic solution to the acid solution there would be the reaction of a neutralization*".

The indicator of theorem-in-action "*the $Ca(OH)_2$ eliminates the acidity of the acid*" brings the use of wrong terms, because happens the reaction between the acid and the base(the neutralization) lessening the effects of the acid, that is, the acidity on the place will be reduced and not the "acidity of the acid". Such difficulty of explanation might be the reflex of what was observed on the questionnaire of previous knowledge, since the student brought justifications with incomplete ideas for the definition of the acid and basic behavior of the substances, besides not considering that the process of neutralization happens between the substances for this problem.

The TCF assumes the existence of two classes of situations, which are related to the personal competences of the students to solve them. In the first group of situations, the students have enough elements to face them, manifesting an "automated" performance, constituted by an only scheme. The second group is referred to the situations where the individual does not present enough elements to face them, because of that, he/she uses different schemes to solve them (Rocha, & Basso, 2017). For so, the schemes need to be "accommodated, uncombined and recombined", as it is affirmed by Vergnaud (1982, p. 2).

Cedran and Kiouranis (2019) describe in their work that, for Vergnaud, a scheme may present the function, both for organizing and orienting actions in situations where certain familiarity is presented, and also to face situations so far unknown, promoting the adaptation to situations and, through the cognitive development, its expansion to other classes of situations.

The difficulty observed might be related to the necessary schemes for the situation, because the student seeks into his/her cognitive repertoire schemes related to it through the modification/combination of schemes, besides the expansion of cognitive elements for the creation of new schemes. This is established when a scheme has as basis the implicit conceptualization, thus, although the student is not able to express the concept, he/she must understand it for it to "work" correctly (Rocha, & Basso, 2017). For Vergnaud, the development of new schemes enables the student the confrontation of situations with more complex levels, where new operational invariants will be elaborated.

Moreira (2002) explains that besides formulating questions, organizing information, among other actions, the teachers use words and sentences to explain certain contents. However, their actions in proposing productive learning situations for the students is the most important, because, through that, the student can cognitively develop, since until getting to the solution of the situation, he/she uses different schemes, combined, uncombined and recombined (Rocha, & Basso, 2017).

The student Raquel referred to the Calcium Hydroxide as a strong base in her answer, which is classified as it, with an elevated pH by its complete dissociation releasing ions calcium and hydroxyl (Chaves, Fernandes, & Ogata, 2018), even though, on her answer, she had given a simplistic and inconclusive explanation relating it to the presence of hydroxyl. Besides that, the student showed to consider that the addition of the basic solution must be cautious, to not "*put the $Ca(OH)_2$ solution in excess*". In this sense, the student seems to recognize the relevance of the proportion of the substances for the process of neutralization to happen, considering that the base in excess would result in a predominance of the basic medium in the environment.

Considering the definition of Arrhenius, which is the theoretical model closer to the student's answer, it is noticed that she could assimilate them as acids and basics and also classify them as strong. Vergnaud affirms that the familiarity with certain situations approaching the same content will allow the students to elaborate mental schemes, enabling them to use it in a range of other situations with different levels of complexity (Hilger, & Oliveira, 2012). Hence, in the category *Neutralization*, the students based themselves on the process of neutralization for their explanations:

> *The best substance would be $Ca(OH)_2$, because being a base, would neutralize the acid according to the reaction: $H_2SO_4 + Ca(OH)_2 \rightleftharpoons CaSO_4 + 2H_2O$. The calcium sulphate ($CaSO_4$) formed is partially soluble in water, being able to be removed by the current (rains)* (Cláudio).

> *I would use the calcium hydroxide ($Ca(OH)_2$), which is a base, to quickly neutralize the sulphurous acid (H_2SO_4), which is an acid, forming water and salt $H_2SO_4 + Ca(OH)_2 \rightarrow 2H_2O + CaSO_4$* (João).

> *I would create a neutralization of the acid with the $Ca(OH)_2$, this would entail in the formation of an insoluble salt of $CaSO_4$. This, on the other hand, is not harmful to the ground, because it is a commonly used substance in agriculture to fertilize the soil* (José).

> *The best way to lessen the effect of the acid is to add a base, like the $Ca(OH)_2$ that would neutralize the effect of the acid and avoid the damage to the environment* (Pedro).

> *In this case, the substance to be used would be the $Ca(OH)_2$ base. Knowing that the sulphurous acid is a strong acid, having characteristics of proton donor – the acids in general. For so, the chosen base will receive these protons, forming salts and water, in a neutralization reaction, leaving the place safe and clean* (Maria).

With these answers, it was detected the following indicators of theorems-in-action: "*the base would neutralize the acid"* and "*the reaction of neutralization has as its product the formation of salt and water*". It is highlighted that, among the answers of this category, only the student Maria described the theory involved in her explanation (Brønsted-Lowry) since she referred to the acids as a species able to give protons since it is necessary that all the used concept to be delimited to the theory, so it can be attributed sense to the process of neutralization (Liso, & Torres, 2002). It is recalled that the appropriation of the theoretical model used in this question is different from the one used by the student in her definition of acids and bases in the questionnaire about previous knowledge.

The students' answers bring reflects of the justifications for questions 1 and 2, related to their previous knowledge. The student Pedro, although he has not founded his answer in a theory for questions 1 and 2 and used only the pH scale for his definitions of acids and bases for the problem, was able to classify the substances as acid.

Beyond the theoretical scope, Cláudio and João used the symbolism to support their answers, using the representation of the reaction of neutralization. According to the proposed by Arrhenius (1903), strong acids and bases in aqueous solution and, consequently, their salts, present themselves "in extreme dilution almost completely dissociated into their ions", that is, in a reaction between strong acids and bases, according to the precept of the chemical equations, it is possible to suppress the equal ions on both sides of the equation (Dreschsler, & Schmidt, 2005).

It is verified, yet, that the students Cláudio and João represented the formation of the salt and the water with products of the reaction and did not identify the physical states of the substances. The student João did not use the double arrow to indicate reversibility and the simultaneous presence of the species, representing a dynamic balance, similar to what was seen on the work of Silva et al. (2008).

The symbolic representations, according to the TCF, are responsible for making a concept significant and that is established by the interaction between the situations and schemes, being manifested through the language and the symbols that are essential for the process of learning, which the teacher, through his/her mediation, uses constantly to help the students to expand their repertoires of schemes, as well as their representations (Moreira, 2002).

Vergnaud (1982) assesses that a representation is ordained by concepts, because of that it is not possible to imagine, speak about a certain object or symbolize it without concepts, even precedents of it. Thus, the representations are established by the theorems-in-action, that is, by the propositions that are considered true. Because of that, if there are problems in the theorems-in-action, consequently, these difficulties will be reflected in the attempts of symbolic representations, as it was observed on the previous answers (Vergnaud, 1982).

The category *Did not answer* was elaborated to include the answer of the student Débora, that checked the answer "*diesel oil*", not being possible to make inferences about her possible scheme of action to solve the problem. However, the fact that the student checked this option indicates an inappropriate way to solve the problem, since it would not be acceptable for the presented situation. It is important to mention that it occurred even with the use of the Arrhenius theory to justify her answers on the questionnaire of previous knowledge. Therefore, it is necessary to consider the study of acids and bases in a way that leads the students to reflect, debate, and justify their conception, as well as seek to apply in different situations, using their theoretical knowledge.

It is worth to emphasise that when answering the problem 1, the students did not mention the heat involved in the reaction of neutralization, which is presented as an essential factor for the resolution of the problem since those who presented justifications for their answers checked the option that brought the calcium hydroxide, assuming it as the best option among the others, this way, not considering other more variable options as salts and oxides with basic characters, as the calcium oxide (CaO), whose absence in the list of option could have been noticed by the students.

In problem 2, the students should explain the reason why the lemon and the vinegar are good options to the elimination of the smell of fish in the hands of a fictional person, considering that they would represent the answer given by the chemist who was called to solve the question. According to the answers given, three categories were created: *Transformation of the methylamine*, described by one of the students to explain the process on the problem; *Adherence of the acid to the methylamine* and *Neutralization*, as processes responsible for the elimination of the smell of fish from the hands.

The category *Transformation of methylamine* was created because of the following answer, which is founded on the transformation of the methylamine in another substance, from the reaction with the H^+.

> *The vinegar and lemon are acids, they have H^+ in their medium and when the vinegar or the lemon entendered in contact with the $H_3C\text{-}NH_2$ (chemical substance) that is on the hand, there would be a reaction, where the H^+ would transform the $H_3C\text{-}NH_2$ in another substance* (Raquel).

In this answer, it was identified the possible indicators of theorems-in-action: "*vinegar and lemon have H^+ in their medium*" and "*The H^+ transforms the $H_3C\text{-}NH_2$ in another substance*". In the first presented indicator of theorem-in-action, the student classified the vinegar and the lemon as acids and affirmed that they have "*H^+ in their medium*", not explaining what medium she was referring to, what evidences a confusing explanation about the acids, referring one more time to the idea that the acids are substances that contain H^+, similarly to what she pointed on question 1 of the introductory questionnaire, that acid "*would be a substance that presents concentrations of $[H^+]$*".

As discussed before, this type of indicator of theorem-in-action is commonly originated from previous conceptions acquired through the school period that remains in their cognitive structure, suggesting the necessity of applying their knowledge around this concept. Moreira (2002) affirms that in the previous conceptions of the students are included the theorems and concepts-in-action that, although are not yet considered true theorems and scientific concepts, might become, together with the mediator action of the teacher and clarification of the students, even if this conceptual change takes time. However, some previous conceptions act as epistemological obstacles for the learning of certain concepts, needing, consequently, to be abandoned or modified to reach the learning. For this purpose, it is recalled the mediator's action of the teacher as essential (Moreira, 2002).

In an attempt to explain the reaction that occurs between the substances, the student did not refer to the methylamine as a substance with basic behavior, just as a *chemical substance*. Besides that, she attributed to the H^+ the capacity of "*transforming the H_3C-NH_2 in another substance*". Such conception might also become a substancialist obstacle, as it is described by Ribeiro and Gonçalves (2019) based on the perspective of Lopes (2017), which is evidenced by a wrong justification, as considering the basic and acid properties inherent to the proton H^+ and to the hydroxyl (OH^-) present in the molecules. Also, she transmits the idea of transmutation, possibly reflecting on her students the idea that "the substances transform themselves because their atoms transform", not that their atoms rearrange to form new substances (Silva, Souza, & Marcondes, 2008).

Still in regarding previous knowledge, in the TCF it is supported that it must be considered in the process of learning and teaching. According to Ausubel, these are defined as "subsumers" to learn the new concept and significative learning occurs when these concepts interact as new knowledge. However, if the student does not advance to establish a relation between old and new concepts, the learning will be stagnated and will open space for the persistence of the alternative conception along the school period. Thus, the teacher may help the student through the introduction of the contents, taking into consideration the level of complexity, in order to favor the assimilation with the previous concepts (Jenske, 2011).

The answer relevant to the category *Adherence of the acid to the methylamine* was elaborated based on the adherence of the acid to the methylamine, as well as on the solubility of the substance in water:

> *The acid (vinegar or lemon) adheres to the molecule of methylamine making it easier to be removed from the skin. For being soluble in water, that substance is diluted by the water present in the vinegar and the lemon* (José).

A different view about the process that happens between the substances is observed on José's answer, where it was identified the indicators of theorems-in-action "*The acid (vinegar or lemon) adheres to the molecule of methylamine*" and "*the methylamine is soluble in* *water*". The student explains that the removal of the smell, created by the methylamine, is the result of the adherence of the acid to the methylamine molecule, which does not consider the reaction between the acid and the base, mentioning only the aspects related to the solubility and the presence of water in the vinegar and lemon.

The fact that the methylamine is an organic substance with basic behavior, according to the theory of Brønsted-Lowry, may have made it difficult for the student's association between the base and the acid and the consequent reaction between the substances, what really happens, and not the adherence, where happens the bond between the substances. The student's answer on question 2 about the previous knowledge contributes to this conjecture because he defined base as "*constituted by the ion* OH^-".

As it was previously discussed, the confronting of situations with different levels of complexity helps with the elaboration and expansion of the schemes used by the students to the resolution. The student's answer suggests the lack of schemes related to the application of the behavior of the organic substances, recognizing that the content is commonly more explored when compared to the inorganic functions, studied in the last year of high school and better explored in the higher education. In the organic chemistry, the theoretical models that are used to explain the behavior or interaction of the substances are usually the ones pointed by Brønsted-Lowry and Lewis.

Similar to the study of the acid and base content in inorganic chemistry, it is possible to observe the same problems in the organic chemistry, where the students use words to conceptualize acids and bases. Figueira, Oliveira, Salla, and Rocha (2009) pointed out that students from the 3rd year of high school, while studying the organic function "carboxylic acids", started to conceptualize acid as a substance that presents the functional group -COOH, however, none of them represented the ionization of the carboxyl. Consequently, the teachers must propose enriching situations that might promote the development of schemes and generate conflicts, so that existent schemes are molded to new situations that are presented to them (Cedran, & Kiouranis, 2019).

In the category *Neutralization*, there are the answers justified by the reaction of neutralization between the acids present in the vinegar and the lemon and the base for the elimination of the smell of fish.

> *The methylamine is a basic substance, that when in contact with water releases ions* OH^-: $H_3C\text{-}NH_2 + H_2O \rightarrow H_3C\text{-}NH_3^+ + OH^-$. *The vinegar, that contains acetic acid, and the lemon that contains citric acid, neutralize the methylamine, ending the bad smell* (Cláudio).

> *Vinegar and lemon are acids (H^+) and neutralize the methylamine. The methylamine reacts with the acids to create the methylammonium ion, which does not smell* (João).
>
> *The smell characteristic from methylamine is typic from the bases because they release a strong smell. The use of acid as a neutralizer of the base, the vinegar is a weak acid and the lemon is a stronger one. However, both are efficient in the elimination of the smell* (Paulo).
>
> *As the smell of fish is a base and the (solution) substance lemon/vinegar are acids, which neutralize the base, leaving it without the smell* (Maria).
>
> *The lemon and the vinegar are substances of acid character, being able to neutralize the smell of fish* (Débora).
>
> *Because the lemon and the vinegar are acid substances. So, when these products are used, there will be the neutralization of the smell* (Pedro).

In these answers, it was identified different possible identifiers of theorems-in-action: "*the vinegar, that contains acetic acid, and the lemon that contains citric acid*"; "*the acid neutralizes the methylamine*"; "*vinegar and lemon are acids*"; "*the methylamine reacts with the acids to form the methylammonium ion*"; "*the vinegar is a weak acid and the lemon is a stronger one*".

The student Paulo described that "*the vinegar is a weak acid and the lemon is a stronger one*". In Cláudio's answer, there is a bigger approximation of the theoretical model of Arrhenius, where the student classified the methylamine as basic and explained that the vinegar and the lemon contain, and not that they are, acid substances ("*The vinegar, that contains acetic acid, and the lemon that contains critic acid*"), pointing out the process of neutralization between the acid and the base as responsible by the elimination of the bad smell on the hand: "*The acid neutralizes the methylamine*".

The student also presents the same conception of the questions 1 and 2 of the questionnaire about previous conceptions, that acid and base "*release*" H^+ and OH^-, respectively, recalling the definition of Arrhenius, although the phenomenon in question is better explained by the definition of Brønsted-Lowry, where the methylamine receives protons from the water, forming the methylammonium ion and the hydroxyl ion. Thus, when adding the acid (both for the lemon or the vinegar) there is a movement of the balance in the direction of the methylammonium ion, which does not smell.

The student João recognized the vinegar and the lemon as acids and represented them with the proton H^+, recalling the explanation presented on question 1 of the introductory questionnaire, where he said the acids are substances that release H^+ and contain, necessarily, this ion in its molecular formula. The student also explains the elimination of the smell by the process of neutralization, where there is the formation of the methylammonium ion, which is odorless, as observed previously.

On Pedro's answer, when referring to the elimination of the smell of fish, he used the expression "*neutralization of the smell*", not explaining the occurrence of the neutralization reaction between the substances. Although in the previous problem the student Débora had not presented a clear answer, in this problem, the student explained the process of elimination of the smell of fish due to the reaction of neutralization of the acid with the base.

Generally speaking, most of the students presented answers based on the reaction between the substances, however, some justified it incompletely, with little or no chemistry backing to support the resolution, which suggests difficulties in the association between concepts and their application, as discussed before. Studies demonstrate that certain students sometimes understand some phenomena, but they find it difficult to give explanations about it, not attributing the proper relevance to the functionality of the knowledge included in it (Brandão, Araujo, & Veit, 2014).

5. Teaching Implications and Final Considerations

This research highlights the identification of theorems-in-action for the clarification, reflection, and discussion related to conceptualization problem in the teaching of acids and bases, showing that the teacher can contribute to the student's learning, directing him/her to the expansion/modification of theorems-in-action that can act as obstacles in the learning of concepts (Boni, & Laburú, 2017).

Therefore, this paper presents its relevance for the possibility of directing teachers, in initial training, in the approaching of the conceptual field of acids and bases since it was explored possible indicators of theorems-in-action in the students' conceptions that might be identified by them in the mediation of the learning. Then, the results exposed here can contribute with other researches related to the theme and favor a teaching process that considers the theorems-in-action here identified. This question is reinforced when it is considered that the operational invariants are still rare explored in the conceptual field of acids and bases.

In addition to that, the research allowed a brief discussion about the way that the students learn the content and how it could influence their way of teaching, considering that in most of the students' answers conceptual mistakes related to the explored content were identified.

The teacher in training also had the opportunity to discuss aspects related to their learning because the proper moment to the exploration and reflection of different points related to the teaching practice is during the training. When they notice their conception, the students were led to recognize their abilities and limitation to the content, being able to reflect on how the learning happens.

Hence, mapping the possible indicators of theorems-in-action enables the directing of the teacher's activity to favor the enrichment of the students' conceptions and make the theorems-in-action closer to what is scientifically accepted (Alegro, 2008). In relation to the teaching and learning processes, it is necessary to recognize the importance of following the performance of the students and, consequently, evaluate the teacher's teaching acting before the advancements and retreats presented by the students.

Thus, the present research provides researchers in the area with an important subsidy for studies that explore the theme with a view to understanding and monitoring the learning process, as well as the recognition of the importance of the teacher's role in mediation and its limitations, through the identification of theorems-in-action related to the contents explored in the classroom.

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Research, Society and Development, v. 9, n. 12, e45591211331, 2020
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i12.11331

Percentage of contribution of each author in the manuscript

Kariny Mery Araujo Cunha – 40%

Inês Maria de Souza Araújo – 15%

Jerino Queiroz Ferreira – 15%

Luciana Nobre de Abreu Ferreira – 30%