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Methodology focused on the order of chemical reaction from an issue of developing student and teacher skills and competencies

Metodología centrada en el orden de las reacciones químicas a partir de un problema de desarrollo de las capacidades y competencias de alumnos y profesores.

Méthodologie axée sur l'ordre des réactions chimiques, basée sur un problème de développement des aptitudes et des compétences des étudiants et des enseignants.

Metodologia focada na ordem de reação química a partir de uma problemática de desenvolvimento de habilidades e competências discentes e docentes

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Abstract

This study presents a proposal for an action-research approach to teaching practice following a qualitative document research methodology, applying the anthropological theory of the didactic and the theory of meaningful learning to Chemical Kinetics, a curriculum present in Brazilian high school education. Within this practice, developing a methodology to facilitate the calculation of reaction orders, enhancing the roles of teachers and students, raised questions to be answered: What impact does a methodology focused on the order of chemical reaction have, starting from a problem whose aim is to develop skills and competences that promote the formation of teachers and students, provoking a change in attitude towards socio-environmental issues? Many omissions in wise knowledge and few didactic creations related to experimentation and the process of mathematical modeling were identified in the literature

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researched. However, in this work, the teaching time in relation to the content and the learning time of the students was respected, and the strategy proved effective in the meaningful, transposition, and praxeological scopes.

Keywords: Modifications of wise knowing, Mathematical modelling, Skills and competences, Meaningful teaching and learning in chemical kinetics.

Resumen

Este trabajo presenta una propuesta de investigación-acción de la práctica docente siguiendo una metodología de investigación cualitativa documental aplicando la teoría antropológica del didáctico y la teoría del aprendizaje significativo a la Cinética Química, currículo presente en la educación secundaria brasileña. Dentro de este marco de práctica, el desarrollo de una metodología que facilite el cálculo de órdenes de reacción elevando el protagonismo de docentes y estudiantes nos generó preguntas a responder: ¿Qué impacto tiene una metodología centrada en el orden de reacción química a partir de un problema cuyo objetivo es desarrollar habilidades y competencias que promueven la formación de docentes y estudiantes, provocando un cambio de actitud hacia los problemas socioambientales? Se identificaron muchas omisiones en el conocimiento sabio y pocas creaciones didácticas inherentes a la experimentación y al proceso de modelado matemático en la literatura investigada, sin embargo, en este trabajo, se respetó el tiempo de enseñanza en relación con el contenido y el tiempo de aprendizaje de los estudiantes, y la estrategia demostró ser efectiva en los ámbitos significativos, de transposición y de la praxeología adoptada.

Palabras clave: Modificaciones del saber, Modelización matemática, Habilidades y competencias, Enseñanza y aprendizaje significativos en cinética química.

Résumé

Ce travail présente une proposition de recherche-action de la pratique enseignante suivant une méthodologie de recherche qualitative documentaire appliquant la théorie anthropologique du didactique et la théorie de l'apprentissage significatif à la Cinétique Chimique, programme présent dans l'enseignement secondaire brésilien. Dans ce cadre de pratique, le développement d'une méthodologie facilitant le calcul des ordres de réaction en valorisant les rôles de l'enseignant et de l'élève nous a posé des questions à résoudre : Quel est l'impact d'une méthodologie centrée sur l'ordre de réaction chimique à partir d'un problème dont le but est de développer des compétences et des aptitudes qui favorisent la formation des enseignants et des élèves, provoquant un changement d'attitude face aux problèmes socio-environnementaux ? De nombreuses suppressions dans le savoir sage et peu de créations didactiques inhérentes à l'expérimentation et au processus de modélisation mathématique ont été identifiées dans la littérature recherchée, cependant, dans ce travail, le temps d'enseignement par rapport au contenu et le temps d'apprentissage des élèves ont été respectés, et la stratégie s'est avérée efficace dans les domaines significatifs, de transposition et de praxéologie adoptée.

Mots-clés : Modifications de la connaissance éclairée, Modélisation mathématique, aptitudes et compétences, Enseignement et apprentissage significatifs en cinétique chimique.

Resumo

Este trabalho apresenta uma proposta de investigação-ação da prática docente seguindo uma metodologia de pesquisa qualitativa documental e aplicando a Teoria Antropológica do Didático e a teoria de aprendizagem significativa à Cinética Química, currículo presente no Ensino Médio brasileiro. Nesse âmbito de prática, desenvolver uma metodologia facilitadora de cálculo de ordens de reação elevando os protagonismos dos participantes nos gerou questões a serem respondidas: qual o impacto de uma metodologia focada na ordem de reação química a partir de uma problemática cujo intuito é desenvolver habilidades e competências que proporcionam a formação de docentes e discentes provocando uma mudança de postura ante as problemáticas socioambientais? Foram identificadas muitas supressões no saber sábio e poucas criações didáticas inerentes à experimentação e ao processo de modelagem matemática nas literaturas pesquisadas. Porém, neste trabalho, foi respeitado o tempo de ensino em relação ao conteúdo e ao tempo de aprendizagem dos aprendizes, sendo que a estratégia se mostrou eficaz nos âmbitos significativos, de transposição e da praxeologia adotada.

Palavras-chave: Modificações do saber sábio, Modelagem matemática, Habilidades e competências, Ensino e aprendizagem significativa em cinética química.

The study of Chemical Kinetics at the high school and undergraduate levels, in various Chemistry courses, has been approached in a highly formalistic manner and out of context with the realities of the students, their learning trajectories, and gaps such as difficulties in text interpretation, difficulties in mathematically relating formulations, tables, graphs, experimental data, calculations, etc. Due to the limited use of practical classes and facilitating applications, this issue may be linked to the initial training of the teacher or to the absence of adequately equipped laboratories in schools for such execution, or both. Topics with a certain degree of abstraction, such as Chemical Kinetics, end up posing challenges for classroom mediators, the teachers, as well as for the students, who are venturing into new areas of knowledge and require prior foundational knowledge, referred to as prior knowledge. Many teachers report in their practices that the topic of Chemical Kinetics is challenging to approach because it requires the integration of many concepts and not isolated parts of knowledge, as Justi and Ruas (1997, p. 24) note, and requires an appropriate didactic transposition from scholarly knowledge to teaching knowledge, and from this to the taught knowledge.

This situation has immediately cascaded into difficulties for addressing other topics such as Chemical Reactions in their Reaction Mechanisms, Chemical Equilibria, and Electrochemistry. In a deeply empirical discipline like Chemistry, mere reproduction of knowledge or inadequate transposition is insufficient. Thus, there is a corroborated demand for highly interactive and diversified teaching and learning processes that work from realities, prioritizing stimulating tools and strategies that lead learners to a reading of the world they live in and to the construction of knowledge, and encourage teachers to move from being informers to becoming educators (Chassot, 2018, pp. 84-90).

Furthermore, the use of simple experimental practices as substitutes for more complex ones and the mediation of topics in this discipline through other themes or technological practices, such as those related to environmental conservation and thus involving Science, Technology, Society, and Environment (STSE), Environmental Education (EE), and Mathematical Modeling, is important. For this, the use of a well-detailed practice grounded in a historical, creative theory that is well accompanied is essential. According to Veiga (1991),

> theory should serve as a guide to practice, and practice as the guided action mediated by theory. The demonstration itself demands of the teacher a series of tasks such as: clarifying the objectives of the demonstration; presenting the demonstration outline so that the student gets an overall view of the activity, facilitating the logical understanding

> of the content; explaining the basic mechanisms of the demonstration being conducted, emphasizing the most important details to observe or reinforcing certain technological, scientific information essential for understanding the demonstration and learning new operations, and insisting on adherence to safety norms. Then, the demonstration begins at a pace that allows the students to follow along, illustrating with available resources, questioning them, explaining what is being done, reinforcing the explanation of unclear parts, and relating it to the study object as a whole, confirming explanations, making them more real and concrete, stimulating critical thinking and creativity. In conclusion, it clarifies concepts, principles, using exemplifications, research results, and studies, establishing cause and effect relationships, making analogies, recognizing and valuing originality (p. 141).

The concept of reaction rate often seems strange to a high school student, possibly due to prior knowledge acquired in kinematics in the Physics course, and, depending on the approach, if misunderstood, it can also lead to specific misinterpretations and false conceptions for these students as well as for undergraduates in Chemistry and related courses. The concept of reaction rate is extremely important (Kaya & Geban, 2012, pp. 216-225) for dispelling misconceptions related to the study of Chemical Kinetics and related topics.

In this context, our research was conducted through the development of educational activities involving the topic of Chemical Kinetics that have a direct connection with other sciences. The locus of its execution was at a campus of the Federal Institute of Pará, located in the municipality of Abaetetuba, Pará (PA), Brazil, during the academic semester from February 6, 2023, to June 27, 2023. The study encompassed other subsuming themes, which were Chemical Quantities, Reaction Stoichiometry, and Units of Concentration or Study of Solutions, logarithms, and the application of the trigonometric Tangent of an Angle relationship. These works involving Chemical Kinetics were partly based on a master's thesis by the first author. During the mediation of teaching and the development of dialogues to enhance learning, EE was incorporated, as it is a political requirement and deals with the formation of reflective and participatory citizens, not just seekers of concept acquisition (Reigota, 2016, pp. 13-14).

It is emphasized that this action research, which has a social and scientific commitment (Thiollent, 2011, pp. 7-9), also plays the role of facilitating teaching and learning, as from it and other demands, teachers across the country had to reinvent and relearn by adopting new technologies. This work, which yielded significant learning outcomes, aimed to awaken students' interest in environmental causes and promote the formation of a more comprehensive and holistic conception of reaction speed.

For the construction of this research, we relied on the theory of Meaningful Learning (Ausubel et al., 2016), as it has theoretical constructs that allow us to analyze the significance of concepts and the development of thought. We also relied on the Anthropological Theory of the Didactic and the Theory of Didactic Transposition.

We promoted the construction of Concept Maps (Moreira, 1980, pp. 474-479), which are two-dimensional diagrams that provide the representation of relationships between concepts through propositions on a specific topic, and Comic Books (CB). These served as one of the teaching strategies, assessment, study, among other functions, aimed at improving the teaching and learning of Chemistry.

In the assessment of teaching and learning, we opted to adopt a methodology of assessment based on a constructivist-sociointeractionist approach to education, diagnostic, formative, processual, liberating, aware of social and cultural differences. For this, the evaluative action was considered in its dialogic and interactive function, with the intention of promoting the moral and intellectual development of learners in a participative, social, and political manner (Hoffmann, 2019, p. 34).

In addition, a set of videos, consisting of various prior lessons, was made available. These materials were developed to adapt to the flipped classroom format, as described by Cortelazzo (2018, p. 115). This resource provided a dynamic and engaging learning environment for students.

In this context, the present work focuses on a central question, which seeks to elucidate the practical and pedagogical effects of an innovative educational approach. Therefore, the research question guiding this investigation is: 'What is the impact of a methodology that focuses on the chemical reaction order, starting from a specific problem, with the intention of developing skills and competencies that assist in the training of teachers and students, and that aims to induce a change in attitude towards socio-environmental issues?' This question will guide our analysis, allowing us to explore the nuances and effects of this methodology, both in terms of individual learning and the broader formation of a more critical and active socio-environmental consciousness.

In this part, we discuss theoretical constructs of Didactic Transposition, Anthropological Theory of the Didactic, and the Theory of Meaningful Learning. These are essential in the construction of this text.

Didactic Transposition Theory and Anthropological Theory of Didactics

In detail, we will provide a brief overview of the foundations of the Didactic Transposition Theory (Chevallard, 1991) and the Anthropological Theory of Didactics. For this purpose, we base our discussion on the references “Fundamental Concepts of Didactics:

perspectives brought by an anthropological approach" (Chevallard, 1992) and "The analysis of teaching practices in the anthropological theory of didactics" (Chevallard, 1999).

Firstly, we must consider the history of the development of the term **transposition**, which in our case refers to certain modifications and adaptations of knowledge to make it teachable or suitable for schooling, thus formalizing the basic assumption of didactic transposition. In his work, when developing his theoretical model, Chevallard emphasizes didactics focused on the education system or didactic system, a product of the prevailing society, and highlights the issue of school knowledge in the field of pedagogical reflection, a subject of didactics.

It is worth noting that the term "Didactic Transposition" was first used by the French sociologist Michel Verret (2006) in his doctoral thesis "Les temps des études," published in 1975 by Atelier Reproduction des thèses, Université de Lille III, where he proposed to conduct a sociological study on the distribution of time in school activities. For Chevallard, the search for the roots of knowledge is found in scholarly knowledge, which requires a robust epistemological analysis of knowledge in its latent form and, in a way, reveals a deeply complex universe that leads to a confirmation of a break or distance from the knowledge prevailing in schools or popular culture.

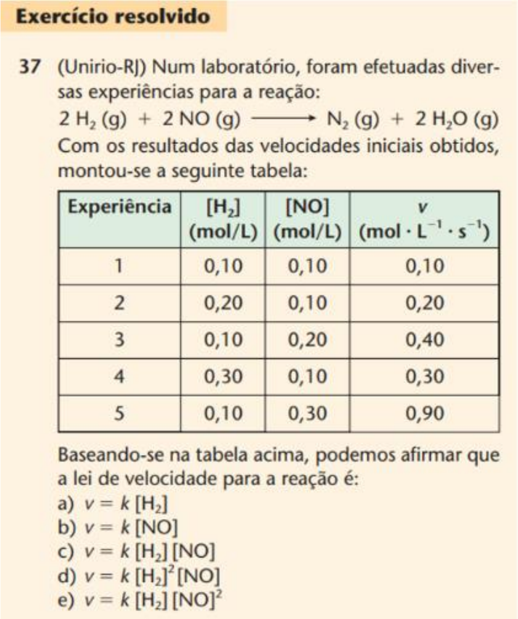
When Chevallard discusses the presuppositions about teachable knowledge and didactic preparation based on Verret's ideas, he warns that the administrative, didactic, pedagogical, and disciplinary organization of the institution that formalizes the rights and duties of all those living in the school or institutional environment, and therefore constitutes the didactic regime, leads to the transmission of teachable knowledge and unteachable knowledge or, at least, non-schoolable knowledge, which meets the methods of scientific reproducibility. According to Verret (1975), cited by Chevallard (1991), school transmission of knowledge implies:

> a) The division of theoretical practice into delimited fields of knowledge that give rise to specialized learning practices, i.e., the desincretization of knowledge;
> b) The separation of knowledge from the person, in the scope of practices, i.e., the depersonalization of knowledge;
> c) The programming of learning and its control, according to rational sequences that allow progressive acquisition of knowledge, i.e., the programmability of knowledge acquisition;
> d) The explicit definition, in terms of understanding and extent, of the knowledge to be transmitted, i.e., the publicity of knowledge;
> e) The control and regulation of learning, according to verification procedures that authorize the certification of knowledge, i.e., the social control of learning (pp. 146-147).

Therefore, the concept of didactic transposition allows for the articulation between epistemological analysis and didactic analysis. Moreover, the word **didactics** can be translated as the art or technique of teaching, and thus, it concerns the methods and techniques of teaching aimed at enhancing learning. In this process of placing knowledge into specific and clearer fields of learning, it fosters an interpretative activity of knowledge construction, according to Hoffmann (2019, p. 66), which generates a processual and continual evaluation, endorsing each previous stage in its essence of building competencies (Zabala & Arnau 2018, p. 17) and skills to be constructed and formalized. Pedagogical practice can be better developed when research is part of the search for knowledge, which contributes to the continuous training of teachers and reflects on student learning. It is in this context that both teachers and learners can appropriate knowledge that has already undergone several transpositions, as it has already acquired a more "manageable" form, which, once concretized, is ready for circulation.

For Chevallard (1991), the didactic treatment through which scholarly knowledge passes to become taught knowledge provides an opportunity for confrontation between these knowledges. Assessing how much of this distancing occurs can promote reflections for the insertion of new practices and teaching methods and lead to transpositions that indicate the advancement of learning and teaching. For this, Chevallard (1991) advocates for the triangular representation of the didactic system from three poles: the knowledge (S), the teacher (P), and the learner (A).

Direct use of kinetic data by learners puts them in a situation of false learning regarding the determination of equations or speed laws, as observed in the activities of renowned texts in Brazil, as shown in Figure 1:



Exercício resolvido

37 (Unirio-RJ) Num laboratório, foram efetuadas diversas experiências para a reação:

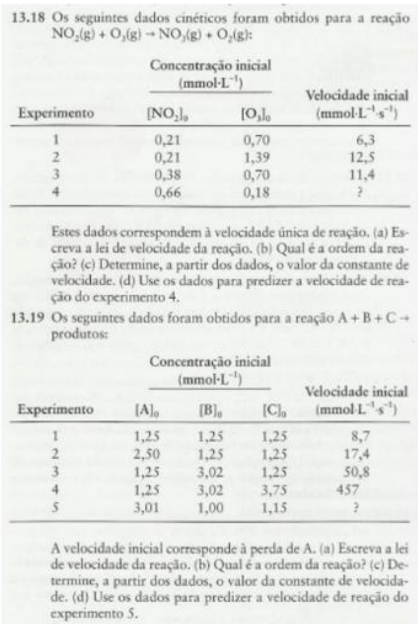
$2\,H_2\,(g) + 2\,NO\,(g) \longrightarrow N_2\,(g) + 2\,H_2O\,(g)$

Com os resultados das velocidades iniciais obtidos, montou-se a seguinte tabela:

Experiência	$[H_2]$ (mol/L)	[NO] (mol/L)	v $(mol \cdot L^{-1} \cdot s^{-1})$
1	0,10	0,10	0,10
2	0,20	0,10	0,20
3	0,10	0,20	0,40
4	0,30	0,10	0,30
5	0,10	0,30	0,90

Baseando-se na tabela acima, podemos afirmar que a lei de velocidade para a reação é:

a) $v = k\,[H_2]$
b) $v = k\,[NO]$
c) $v = k\,[H_2]\,[NO]$
d) $v = k\,[H_2]^2\,[NO]$
e) $v = k\,[H_2]\,[NO]^2$



13.18 Os seguintes dados cinéticos foram obtidos para a reação $NO_2(g) + O_3(g) \rightarrow NO_3(g) + O_2(g)$:

Experimento	Concentração inicial $(mmol{\cdot}L^{-1})$ $[NO_2]_0$	$[O_3]_0$	Velocidade inicial $(mmol{\cdot}L^{-1}{\cdot}s^{-1})$
1	0,21	0,70	6,3
2	0,21	1,39	12,5
3	0,38	0,70	11,4
4	0,66	0,18	?

Estes dados correspondem à velocidade única de reação. (a) Escreva a lei de velocidade da reação. (b) Qual é a ordem da reação? (c) Determine, a partir dos dados, o valor da constante de velocidade. (d) Use os dados para predizer a velocidade de reação do experimento 4.

13.19 Os seguintes dados foram obtidos para a reação A + B + C → produtos:

Experimento	Concentração inicial $(mmol{\cdot}L^{-1})$ $[A]_0$	$[B]_0$	$[C]_0$	Velocidade inicial $(mmol{\cdot}L^{-1}{\cdot}s^{-1})$
1	1,25	1,25	1,25	8,7
2	2,50	1,25	1,25	17,4
3	1,25	3,02	1,25	50,8
4	1,25	3,02	3,75	457
5	3,01	1,00	1,15	?

A velocidade inicial corresponde à perda de A. (a) Escreva a lei de velocidade da reação. (b) Qual é a ordem da reação? (c) Determine, a partir dos dados, o valor da constante de velocidade. (d) Use os dados para predizer a velocidade de reação do experimento 5.

Figure 1.

Activity inherent to the solved exercise on the right (Feltre, 2004, p. 166) and the proposed exercise on the left (Atkins & Jones, 2006, p. 618)

In regards to this work, we proposed to use an alternative path, contrary to what is most common in the current didactic system, but with high cognitive significance, particularly starting from an activity in an environmental context. Subsequently, we applied experimentation with a similar mathematical treatment, which has now become prior knowledge perpetrating a somewhat different internal didactic transposition through the teacher's mediation.

The Anthropological Theory of Didactics is founded on three primitive concepts: objects (O), people (X), and institutions (I). The first foundational concept addressed by Chevallard (1992) is that of object:

> Objects, however, hold a privileged position: they are the 'basic material' of the considered theoretical construction. Just as in the contemporary mathematical universe, founded on set theory, everything is a set (even integers are sets), so too, in the universe I consider, all things are objects. People X and institutions I, along with other entities that I will be led to introduce, are therefore objects of a particular type (p. 127).

Chevallard (1992) acknowledges that, in addition to the mentioned concepts, others, such as personal subject-object relations and institutional relations involving institutions and objects, are equally important in the Anthropological Theory of Didactics, with an object only coming into existence when recognized by a person X or institution I. From this perspective, 'everything is an object' and Chemical Kinetics, for example, is an object of knowledge. For Chevallard (1992), we can then expand the concept of didactics and incorporate didactics into the core of anthropology. In this direction, the didactics of sciences and other didactics reside in the field that studies humanity. Chevallard (1992) presents, in the context of the Anthropological Theory of Didactics, the notion of object O, which, in this case, adds to that of knowledge. In the perspective of the Anthropological Theory of Didactics, knowing an object consists, for both a person and an institution, in having a relation with the object.

Consequently, if person X knows object O, there must be a relation R(X, O) between them, and this is analogous to institution I, which, when it knows object O, also brings about a relation RI(O). Chevallard (1992) indicates that an object only exists if it is known by at least one person or institution; in our case, our object is configured in the scholarly and taught knowledge inherent to Chemical Kinetics.

The concept of person is defined from the pair formed by an individual X and the set of their personal relations with the object O, designated by R(X, O). For Chevallard (1992), person X changes over time, and this change depends on the modification and evolution of their personal relations with the objects, which, in our research, aims at modifications in the academic training of the teacher regarding their new experience with knowledge and didactics, and in the learner's learning.

The third primitive concept presented by Chevallard (1992) relates to institutions. For Chevallard, as with the concept of objects, the meaning of the term institution goes beyond the common use of the word. In this direction, an institution can be almost anything:

> A school is an institution, as is a classroom; but there is also the institution 'guided work,' the institution 'course,' the institution 'family.' Everyday life is an institution (in a given social environment), as is the state of being in love (in a given culture), etc. (Chevallard, 1992, p. 129).

For Chevallard (1992), knowledges are a special category of objects that can be learned and taught, yet cannot be known without being learned. This directly relates to the teaching of Chemical Kinetics based on the premises already listed. Chevallard (1992) conveys the idea that an object or set of objects can be used if it is produced. According to the author, any knowledge S is associated with an institution called P(S), the institution of S's production. Thus, knowledge is something that is produced and moves within institutions. In this perspective, Chevallard (1999) proposed the notion of praxeological organization as a key concept for studying the institutional practices related to a knowledge object. The praxeological approach is thus a model for analyzing institutional human activity. According to the author, there are four interdependent components that constitute it: types of tasks, techniques, technologies, and theories. In this work, we focus on their definitions and uses in praxeological analysis:

1) A task (t) or type of Tasks (T) is expressed by a verb, for example: perform a calculation; develop an expression indicating a phenomenon from experimental data extracted from scholarly literature, conduct a time measurement in a chemical reaction; study a theory or attend a teacher's lecture; elaborate a model related to a climatic phenomenon or some interfering state of environmental equilibrium, etc., which, when applied to the classroom institution, constitutes a problem that 'is a natural object of didactics' (Chevallard, 1999, p. 223).

2) Given a task (t) of a type of Task (T), a praxeology relative to the t of T requires a way to perform the task t of T by a technique (τ), which corresponds to the act of knowing how or to a skill.

3) A set of instruments, methods, and techniques aimed at solving tasks constitutes a technology. Chevallard (1999) argues that the term generally indicated by θ is the rational discourse in relation to the technique (τ), consisting of explaining, making intelligible, clarifying the technique.

4) The technological discourse, or technological apparatuses, is founded on some theoretical reference or theory (Θ). The theory, according to Chevallard (1999), will support the technology and play a fundamental role in relation to the technique, occurring a relationship of interdependence between technique-technology-theory, generally sufficient to address the proposed task. The Theory of Reaction Kinetics or Chemical Kinetics provides the necessary methods for understanding the speeds and mechanisms of reactions.

With these definitions, we developed our work. In the next section, we will continue with the theoretical discussion.

The Theory of Meaningful Learning and the Application of Subsumers and Other Teaching and Learning Facilitators

The Theory of Meaningful Learning, by establishing the learner’s prior knowledge as a reference, clearly states that this is a basic and determining element in organizing education. According to Ausubel et al. (1980): 'If I had to reduce all of educational psychology to just one principle, I would say this: the single most influential factor on learning is what the learner already knows. Find that out and teach accordingly' (p. x).

Meaningful learning is only possible when new knowledge relates substantively and non-arbitrarily to existing knowledge. For this relationship to occur, there must be a predisposition to learn. At the same time, a teaching situation marked by learners as potentially meaningful is required, taking into account the context in which the student is situated and the social use of the object of study. Novak & Gowin (1996) propose a relationship as a reciprocity between teacher and student involving educational materials, with the specific aim of sharing meanings. When this purpose is achieved, the student is ready to decide whether or not they want to engage in meaningful learning (Moreira, 1999, p. 37). The process requires human mediation by the teacher, who is knowledgeable of the accepted and proposed meanings for teaching, and assumes that the learner, upon capturing the meanings indicated by the teacher, opts for meaningful learning.

In this context, prior to the mathematical proposal for determining reaction rates and the didactic choice of teaching and learning facilitators, this could not be

arbitrary as Ausubel's theory suggests, but should be non-literal, i.e., substantive. This could be done through an introductory topic that relates to situations already experienced by the learners and coherent with their realities, since they live geographically in the Lower Tocantins region in the state of Pará/Brazil, near a conglomerate of companies processing bauxite for aluminum extraction, which are also sources of chemical agents contributing to atmospheric environmental degradation. Furthermore, the depletion of the ozone layer is a long-standing and current topic reported in the media as an anthropogenic action potentially dangerous to the sustainability of life on our planet.

According to Zuin et al. (2009), the environment we live in, whether natural or constructed, offers a range of topics that can be applied to the curricular content of Elementary and Secondary Education, interconnecting scientific, technological, social, and environmental issues, which can greatly contribute to the development of chemical concepts and the building of citizenship. An alternative to link meaningful learning to Chemistry is to apply the STSE (Science, Technology, Society, and Environment) approach simultaneously, where society is the central point of the educational process, and the student is, above all, a citizen who needs to develop skills, competencies, and critical thinking. In this respect, investigative experimentation is essential to discuss how science is constructed and to understand its limitations (Ferreira et al., 2010). From this point, the learner may understand that scientific knowledge or scholarly knowledge is not an absolute truth but a continuous construction that often requires conceptual and historical ruptures to evolve (Kuhn, 2006).

In the STSE approach, the teacher can act alternatively to a traditional teaching model, structuring Chemistry content around social themes. A very important milestone, which came to consider the understanding of the natural environment as fundamental to Basic Education, was the inclusion of environmental issues in the Brazilian Education Guidelines and Framework Law (LDB) No. 9394/96. In this context, the use of environmental issues as facilitators of teaching and learning for the construction of educational scenarios in Chemistry is based, according to Pedrini (2000), on the principle that there is no science without man, his work, and nature, and that contents and concepts should be considered basic instrumental for understanding the relationship between nature, knowledge, and society. We also use, in this work, for the verification of existing or improved skills and competencies attached to the production of experimental reports, Comic Books and Concept Maps as evaluative requirements of teaching and learning.

Comic Books (CB) can offer playful and linguistic applications that are highly valuable for teaching and learning. Texts and images, which are static, can represent a reality (whether faithful or imaginary, real or semi-real), thus enabling the reader's insertion/participation in the narrative (Quella-Guyot, 1994). Groups of learners were encouraged to develop and construct their CB using the Pixton Comics website[4].

This facilitator led them to expand their creativity and analytical capabilities, synthesis, classification, decision-making skills, and many other mental activities necessary for a correct understanding of the narrative and the created situations that notably form part of their experiences and life contexts. It also opened up the possibility for the artistic creation of their CB manually, while noting that not everyone has the skills for drawing production, which, on a website, would affirm collective production. Concept maps were proposed by John Novak in the 1970s and can be used as tools for teaching and learning and/or assessment, and also to graphically represent concepts and their relationships.

According to Luckesi (2018), learning verification still predominantly occurs through the recording of grades, and the assessment of teaching and learning is conducted in a traditional manner. According to Corrêa (2009), this represents only a classificatory perspective, and cannot be seen as a formative and inclusive assessment. In this context, formative assessment can act as support for possible interventions and resolution of learning misunderstandings. For the execution of enduring teaching and learning, we find that concept maps have aided teachers and students in identifying problems and in knowledge construction, as per Souza and Boruchovitch (2010).

As a tool for assessing the processes of teaching and learning, Novak (2003) states that the concept map, when constructed by the student during the development of concepts, allows for the identification of valid ideas and misconceptions about certain knowledge, benefiting the dynamic monitoring of the assessment, which, in this case, is ongoing. Therefore, it is indeed possible to establish an assessment of learning, rather than merely performing a learning verification, as emphasized by Luckesi (2011) when referring to traditional teaching methods.

Thus, these were also added to the other assessment instruments, in such a way that the assessment was not conducted in a punctual manner, i.e., with a single assessment instrument.

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[4] Available on the World Wide Web: http://www.pixton.com/br/company

Among the many examples of CB produced by the learners, we present one in which the artistic production reports knowledge stemming from skills and competencies developed and acquired over the course of teaching and learning. In the plot of this CB, constructed by the learners, there is also knowledge related to global warming and kinetic data, particularly regarding the lifespan of a chlorine atom, which is around 103 years (Figure 2).

Figure 2.

Comic book produced by a group of learners from the Computer Maintenance and Support course, created on the Pixton Comics™ website (Private collection)

Additionally, a concept map, constructed by the same group, presented the possibility of identifying many ideas formalized during the lessons and developed by the learners, but it reveals a misconception about the term Chemical Kinetics; the learners position it as 'present in the depletion of the ozone layer,' as if it were also an anthropogenic agent, a fact that does not correspond with it, as it is a human theory. In this concept map, we return diagnostically to the subject and engage procedurally and formatively with the knowledge, eliminating false conceptions (Figure 3).

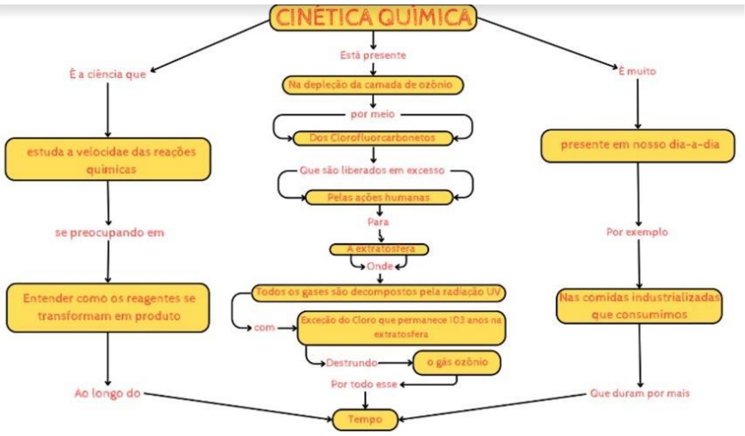


Figure 3.

Concept map produced by a group of learners from the Computer Maintenance and Support course

Regarding the new reality of transitioning from face-to-face to remote education, Tamashiro and Sant'Anna (2021, p. 15) assert that it is not limited to a mere methodological concern. There is an urgency to structure online and distance learning classes, facing a daunting diversity of situations that, in everyday school life, went unnoticed.

Methodology

This study is the result of action research in which researchers and participants are involved in solving a problem in a participatory and cooperative manner through information exchange. The approach is qualitative, as even though the data obtained at times were quantified by both researchers and students, such as kinetic treatments, emphasis is placed on its formative and therefore conscientizing character, focused on the learners' interpretations and on teachers' access to this material, potentially enabling changes in attitudes towards teaching and learning. In this act of interpreting, we seek to assign meanings to the observed and collected phenomena, fostering awakening, motivation, and curiosity of the learner in everyday situations related to the study of Chemical Kinetics (Delizoicov & Angotti, 1990).

The activities developed were planned according to the curriculum present in the PPCs and were implemented both from the theoretical exposition perspective of the STSE approach and experimentally. We were careful not to interfere in the choice of elements participating in the work teams, so that their formations in the groups were random and ensured the confirmation or refutation of our hypotheses (Cajueiro, 2012, p. 19). The participants involved totaled 73 second-year high school learners integrated into the courses of MSI, Informatics, and Buildings at the Federal Institute of Pará (IFPA), Campus Abaetetuba. With them, the theories of Yves Chevallard were applied regarding the analysis of External Didactic Transposition (EDT) and Internal Didactic Transposition (IDT) respective to scholarly knowledge and taught knowledge and the application of the notion of praxeology, which allows us an examination from a theoretical dimension of knowledge with its practical dimension (know-how). Chevallard (2006) states that

> [en] la teoría antropológica do didáctico no puede existir acciones humanas sin ser, al menos parcialmente, <<explicadas>>, hechas <<inteligibles>>, <<justificadas>>, <<contabilizadas>>, en cualquier estilo de <<razonamiento>> que pueda abrazar dicha explicación o justificación. La praxis, por tanto, implica el logos que, a su vez, implica volver a la praxis. En efecto, toda praxis requiere un apoyo em el logos porque, a la larga, ningún quehacer humano permanece sin cuestionar. Por supuesto, una

> praxeología podría ser deficiente, por ejemplo, por su <<praxis>> se compone de uma técnica ineficaz - <<técnica>> es aquí la palabra oficial para designar uma forma de <<saber hacer>> - y su componente <<logos>> conta casi completamente de puro sinsentido - ¡ al menos desde el punto de vista del praxeológico! (p.23).

Regarding the use of teaching and learning facilitators, the Theory of Meaningful Learning by David P. Ausubel et al. (1980) was applied to the Chemical Kinetics curriculum through an adaptation of the active flipped classroom methodology. This was because the post-homework period also consisted of dialogues and general theoretical and practical expositions on physicochemical and environmental themes, mathematical treatments, concept maps, comics, and experimentation, which was not limited to merely clarifying doubts.

The use of technological media platforms thus became a legacy of the pandemic period, constituting multichanneling (Tamashiro & Sant'Anna, 2021). These platforms greatly facilitated the dissemination of productions by teachers and learners. The most used video platform in this work was YouTube, an online video platform where users can create, share, and view videos over the internet. However, the most effective means of sending video lessons in advance for learner interaction on the subject and classroom dialogues was, by far, WhatsApp, a smartphone application used for exchanging text messages instantly, as well as videos, photos, and audio through an internet connection (Júnior et al., 2020, p. 35).

The generating theme, which would serve as the hook for the development of Chemical Kinetics, was chosen due to the difficulty both of learners in understanding and solving problem situations involving Chemical Kinetics and of teachers in associating this curriculum with environmental issues, as it is a content area involving mathematical calculations and is often distanced from the real issues experienced. The classes were then developed in such a way as to make the content available in advance on a video channel and a social network for students who preferred it. In the first formal class, a pedagogical moment occurred with the presentation of the problematization (Delizoicov & Angotti, 1990); through the generated dialogues, an immediate diagnosis of the learners' prior knowledge on the generating theme 'Depletion or degradation of the Ozone Layer' was facilitated. At this time, kinetic data and questions about how these were obtained were presented through questions to the learners; if they could not immediately reach the answers, the instructing teacher would discuss the technological methods of obtaining them.

During this phase, a mathematical treatment was developed, with a session of exposition and dialogue that lasted 100 minutes, corresponding to 2 periods. Subsequently, a practical class of the same duration took place in the laboratory, where the experimental activity with sodium thiosulfate pentahydrate and muriatic acid was presented and developed. This experience provided students with a practical understanding of how to perform and calculate kinetics, fostering hypothesis generation on their part. This was evident in the reports that the students prepared after the practical class.

After the practical class, two more 100-minute sessions were spent on practicing resolutions of activities related to the bibliographies of Ricardo Feltre and Peter W. Atkins & Loretta Jones concerning Chemical Kinetics, questioning the students on how the kinetic data are presented in these works and how our teaching and learning proposal was different and based on formative, environmental, and social character. In the meantime, the learners were challenged to create their own comic books and concept maps about the subjects studied, these facilitators being already familiarized in their practices and assessments with the instructing teacher, being added to the other tasks for the formalization of their quantitative concepts.

Detailed analysis of TDE in tables from the higher education manual and the High School manual adopted in the Pedagogical Projects of the courses related to Building, MSI, and Computer Science

In this topic, which corresponds to the analysis according to the Theory of Didactic Transposition (TTD) and regarding the TDE of the wise knowledge of Chemical Kinetics in General Chemistry, observed in the Title Principles of Chemistry - Questioning Modern Life and the Environment (published by Bookman in 2006 and written by Peter W. Atkins and Loretta Jones) and the knowledge to be taught in the Title Chemistry. Physical Chemistry. 2nd Year (published by Moderna in 2004, authored by Ricardo Feltre), the reference points to observe the concept of reaction rate considering the following aspects: 1) how the concept is structured in the text of academic knowledge and prerequisites; 2) location of the concept in the text of knowledge; 3) models and theories associated with the concept in the domain of academic knowledge; 4) presence or absence of experimental data; 5) origin of experimental data if they exist and, finally, how these experimental data were obtained and verifying if there are adjustments. These bibliographies are available to learners in the IFPA library collection, Abaetetuba Campus.

Table 1.

Detailed analysis according to the TDE of the higher education manual (Wise Knowledge) Principles of Chemistry - Questioning Modern Life and the Environment (Atkins & Jones 2005, p. 577-624)

1ºAspect:	2ºAspect:	3ºAspect:	4ºAspect:	5ºAspect:

The description of chemical reaction rates is presented by expressions that predict the composition of a reaction mixture at any given time and the steps by which reactions occur. The goal is to present reaction rates at both the atomic level to explain the mechanisms and at the macroscopic level. The authors of the book assert that there is no dependency on other knowledge, but it would be useful to review the kinetic model of gases, a fact that, in truth, is not sufficient, as there is clearly a need for mathematical and physical knowledge, understanding of atomism, graphical analysis, and familiarity with mathematical modeling.	The concept of chemical reaction rates appears only in the "Chemical Kinetics" section (Chapter 13) of the work, discussing initial or instantaneous reaction rates on pages 581-582; reaction rate on page 577; and average reaction rate on page 578.	Application of the reaction rate measurement model based on the relationship between molar concentration and time. Reaction mechanisms. Rate laws. Steady-state model applied to elementary reactions and Chain reactions. Molecular Models involving Activation Energy, Collision Theory. Transition State Theory and Catalysis.	There is the presence of experimental data throughout the text, which is indeed important as they are associated with real systems.	In this section, there is no indication of the origin of the experimental data unless stated. Regarding environmental data, the source articles are mentioned on pages 612-613. Also, there is no demonstration, solved activity, or proposal presented on how the kinetic data were experimentally worked on and produced. The text contains few transpositions and can be exemplified by atomic-molecular characteristic models already found in books from the mid-1990s.

Table 2.

A detailed analysis according to the Teaching Didactics of the high school Chemistry textbook "Físico-química" for the 2nd Year (Feltre, 2004, p. 144-179)

1ºAspect:	**2ºAspect:**	**3ºAspect:**	**4ºAspect:**	**5ºAspect:**
The description of chemical reaction rates is presented through expressions that predict the composition of a reaction mixture at any given time and the steps by which reactions occur. The text attempts to explain how reactions take place. It discusses the effects of various forms of energy on reaction rates, the concentration of reactants on reaction rates, and the role of catalysts in reaction rates. Additionally, there is a discussion about automotive	The concept of chemical reaction rates appears only in the "Chemical Kinetics" section (Chapter 04) of the book, addressing the average rate of a chemical	The application of the rate of reaction measurement model based on the relationship between molar concentration and time, mechanisms of reaction, rate laws, the steady-state model applied to elementary reactions, and chain reactions are discussed. Molecular models	The text lacks experimental data throughout, but includes a set of experimental activities, albeit very simple ones, which do not facilitate understanding of the numerous	The text lacks the indication of the origin of experimental data. Additionally, there is no demonstration, solved activity, or proposal that shows how kinetic data were worked on and produced. The text contains many transpositions, which can obscure and lead to false

catalysts. The author does not directly indicate whether there is a dependence of the topic on other previous knowledge; however, there is a clear structuring of knowledge, where the whole is divided into parts, and previous subjects are addressed in the preceding chapter on solutions. There are no experimental models presented in the text.	reaction. However, it draws comparisons with Physics, which may lead to misconceptions and false understandings among students on pages 145-149.	involving activation energy, collision theory, the theory of the activated complex, and catalysis are also covered. Additionally, the effects of concentration, electricity, and light on reaction rates, along with the application of exponential equations, are explored..	kinetic tables found in the text.	conceptions among learners, such as comparing concepts with Physics. Exemplifications of atomic-molecular models are evident.

Table 3.

A detailed analysis according to TDI of the facilitative materials built in video lessons for high school chemistry regarding the subject General Chemical Kinetics. Physical Chemistry. 2nd Year (Junior, 2023)

1ºAspect:	**2ºAspect:**	**3ºAspect:**	**4ºAspect:**	**5ºAspect:**
The video lesson presents a description of chemical reaction rates through expressions that predict the composition of a reaction mixture at any given time and the steps by which reactions occur. It attempts to explain how reactions happen. The effects of reactant concentration on the rates of chemical reactions and the effects of catalysts on the rates of chemical reactions are discussed, including an application of a biological catalyst, catalase. The author of the title directly addresses the topic's dependence on other prior and subsequent knowledge, such as chemical equilibria. There is a demystification of knowledge, meaning the textualization of knowledge in which the whole is structured into parts based on prior knowledge, such as the study of chemical quantities, solutions, and inorganic functions, which are also part	The concept of chemical reaction rates appears throughout the work. There is treatment of the average rate of a chemical reaction. The distinction between the concept derived from Chemistry and that demonstrated in Physics is clearly made, expanding this idea in the	Application of the rate measurement model of reactions based on the relationship between molar concentration and time. Reaction mechanisms derived from environmentally relevant chemical reactions. Laws of reaction rates. Application of the steady state model to elementary reactions and chain reactions. Molecular models involving Activation Energy, Collision Theory, however, a counterpoint to the model is made in the narrative, as particles interact electromagnetically and do not collide as point	Experimental data is present throughout the text, along with a proposal to carry out a set of experimental activities that are simple yet promote understanding of the formation of a kinetic data table and the development of skills and competencies for tackling more complex problem situations and	The origin of experimental data is indicated in the proposed experimental activities and during the modeling processes, either in the written portion of the material or in the narrator's dialogues in the video lessons. The text features numerous transpositions without allowing the emergence of obfuscations and false conceptions among learners. Exemplifications of atomic-molecular models are highlighted.

of the methodology in dialogues following homework. There are numerous examples of experimental modeling inherent in the text, carried out in the Crocodile Chemistry software, with clear proposals and the use of experimental practice coherent with the formation of concept-fostering skills and competencies, as well as the use of mathematical modeling. There are also activities proposed in exercises for submission via digital means or in the classroom.	narrative to other fields and preventing obfuscations and false conceptions among learners.	particles do, Catalysis. Effects of concentration, surface area, temperature, electricity, and light on reaction rates. Explanation of the Van't Hoff Rule. Application of Exponential Equations and linearization based on real data.	interpreting this data.

In the first two tables, it is clear that, although these authors introduce some cross-cutting themes and molecular models in their approaches, the practice of technicality and the culture of testing reproducible knowledge prevail, facts well noted during their consultations, so that the activities do not list problematizing situations. In the High School-related title, the focus lies on pre-college entrance exams.

The video work, related to the third table, presents elucidative dialogues and clarifies doubts explored by the narrator, albeit in monologue form; and there is the use of facilitators that lead to the creation of hypotheses by the learners. Activities are also made available for testing due to the courses' own requirements, in their PPC, that include the integral formation of High School and preparation for the Enem, but in a more contextualized way.

Praxeological analysis of tasks (T), techniques (τ), technologies (θ), and theories (Θ) inherent in the path adopted by the teacher and carried out by the learners per set of tasks (T) inherent to the Building, MSI, and Computer Science classes.

This study aims to explore the application and interaction of various tools and concepts in learning. In this research, we will investigate how tasks, techniques, technologies, and theories intertwine and influence the educational trajectory chosen by the educator, as well as how these practices are received and executed by the students. The focus of this analysis will be especially directed towards student groups in Building, MSI, and Computer Science courses. This study will allow a deeper understanding of the educational dynamics, providing valuable insights into the most effective and beneficial teaching methods for the formation of these students, considering the particularities of each of these fields.

Let's start with the **first set of Tasks (T).** PowerPoint presentations were developed by the lead teacher.

Figure 4.

Video presentations (Júnior, 2023)

Table 5.

Tasks (T), Techniques (τ), Technologies (θ), and Theories (Θ) to be used by the teaching expertise"

		Teacher				
Tasks (T)	t1	The transposition of expert knowledge into teaching knowledge is achieved through the development of presentations and videos containing content on the topic, as well as through experiments followed by submission via WhatsApp.	t2	Archiving videos on a YouTube channel	t3	Posting the videos on a YouTube channel for a minimum of five days
Téechniques (τ)	Bibliographic analysis. Applications of Analytical Chemistry techniques to experiment preparation, its solutions, and biosafety. PowerPoint handling. Video capture from presentations using aTube Catcher software. Conversion of video to MP3 audio format using Format Factory software. Improvement of MP3 sound from the original video using Audacity software. Preparation of the video for availability through rendering using Sony Vegas software. Partitioning of rendered video into smaller videos for WhatsApp sending. Smartphone handling			Managing videos on the YouTube channel		Archiving and making available the videos produced within the specified period for student study
Technologies (θ)	t3	Student Engagement. Access to Educational Resources. Collaboration and Communication. Personalized Learning and Future Readiness		Educational resources and audiovisual resources.		Collaboration, communication, and personalized learning
Theories (Θ)	t4	Chemical Reaction		Computer		Computer

	Kinetics. Computer Science. Analytical Chemistry.	Science	Science

Table 6.

Tasks (T), Techniques (τ), Technologies (θ), and Theories (Θ) to be used by the learner's expertise

		Student		
Tasks (T)	t1	Receiving and appreciating video lessons by learners in a flipped classroom setting	t2	It wasn't necessary, but the learner who wanted to use YouTube videos would count task t1
Téechniques (τ)		Smartphone handling		Handling videos on the YouTube channel.
Technologies (θ)	t3	Access to Educational Resources. Collaboration and Communication. Personalized Learning. Future Readiness.		Collaboration and Communication, Personalized Learning
Theories (Θ)	t4	Chemical Reaction Kinetics. Computer Science. Analytical Chemistry addressed in the subtopics of solutions and reaction stoichiometry.		Chemical Reaction Kinetics. Computer Science. Analytical Chemistry addressed in the subtopics of solutions and reaction stoichiometry.

In relation to the **second set of Task types (T),** after choosing the theme, filming, conducting the experimentation, creating the presentations, recording, rendering, and partitioning for sending via WhatsApp and publishing on YouTube, we moved on to the fourth task (t4) for the teacher and task (t2) for the learners (Table 7), which involve classroom dialogue about ozone layer degradation and raising awareness about its protection through the non-use of Chlorofluorocarbon (CFC) based products, and the importance of reducing chlorofluorocarbon concentrations to contain or decrease the depletion rate of the layer, a phase demanded by subsunctors perceived by learners as potentially significant, constituting an internal transposition, according to the TTD (Chevallard, 1999).

Table 7.

Tasks (T), Techniques (τ), Technologies (θ), and Theories (Θ) to be used by the teaching expertise"

		Teacher
Tasks (T)	t4	o discuss in the classroom the degradation of the ozone layer and raise awareness about its protection through the avoidance of CFC-based products.

Téechniques (τ)		Historical exposition of the evolution of CFC utilization by industries and wealthy or emerging countries. Detailed commentary on the emergence and enlargement of the ozone layer hole.
Technologies (θ)		Specialized scientific reports from surveillance agencies in the field
Theories (Θ)		Chemical Reaction Kinetics. Atmospheric Environmental Chemistry. Analytical Chemistry

Table 8.

"Tasks (T), Techniques (τ), Technologies (θ), and Theories (Θ) to be used by the learner's practice

		Teacher
Tasks (T)	t1	Receiving and appreciating video lessons by learners in a flipped classroom
Téechniques (τ)		Smartphone handling
Technologies (θ)	t3	Access to Educational Resources. Collaboration and Communication, Personalized Learning. Future Readiness. ICT (Information and Communication Technology)
Theories (Θ)	t4	Chemical Reaction Kinetics. Computer Science. Analytical Chemistry addressed in the subtopics of solutions and reaction stoichiometry..

The third **set of Tasks (T)** involved the exposition of mathematical treatment inherent in mathematical modeling. It corresponds to the task (t5) for the teacher and task (t3) for the learners.

Table 9.

Tasks (T), Techniques (τ), Technologies (θ), and Theories (Θ) to be used by the teaching expertise

		Teacher
Tasks (T)	t5	Presentation of the mathematical treatment.
Téechniques (τ)		Whiteboard presentation. Use of tables with kinetic data involving ozone layer degradation. Formation of rate laws. Work with rate constants. Logarithmization. Use of scientific calculator. Linearization. Construction of Cartesian Graph and use of trigonometric tangent relationship to determine reaction order from formed triangles.
Technologies (θ)		Properties of exponential, logarithmic, linear equations, and trigonometric relationships. Relationships involving functions. ICT (Information and Communication Technology)
Theories (Θ)		Chemical Reaction Kinetics. Computer Science. Analytical Chemistry addressed in the subtopics of solutions and reaction stoichiometry. Elementary Algebra.

Table 10.

Tasks (T), Techniques (τ), Technologies (θ), and Theories (Θ) to be used by the learner in their learning process

		Teacher
Tasks (T)	t1	To appreciate and discuss during the teacher's presentation about the mathematical treatment. Provide logarithmic results. Make the Cartesian

		graph and find the tangents on the formed triangles.
Téechniques (τ)		View, listen, and interact in dialogue with contributions and questions..
Technologies (θ)	t3	Properties of exponential, logarithmic, linear equations, and trigonometric relationships. Relationships involving functions. ICT (Information and Communication Technology).
Theories (Θ)	t4	Chemical Reaction Kinetics. Computer Science. Analytical Chemistry addressed in the subtopics of solutions and reaction stoichiometry. Elementary Algebra.

We used concentration data for the species Cl and O3 obtained experimentally according to Atkins and Jones (2001), in the "Chemical Kinetics" section. The teacher's task (t5) and the learners' task (t3) developed with step-by-step mathematical demonstration, which is one of the most important phases of this work and also occurred in the classroom, using the whiteboard followed by explanatory dialogues and questions from the learners, as described below.

In **step 1,** data was taken for the rate constant of the reaction, K1, where the experimental value is 6.49x10^6 mol/L·s and the concentration of ozone gas [O3] = 8x10^-11 mol/L, which are fixed at a temperature of 0°C and an altitude of 45 km. The experimental data (Table 11) of the chlorine concentration inherent to different moments extracted from the atmosphere under the mentioned physical conditions are presented in a table with their respective velocities based on the data from Atkins and Jones (2001):

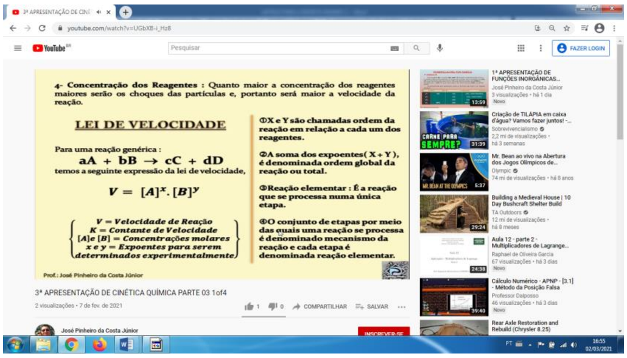
Table 11.

Concentration and reaction rate data (Atkins & Jones, 2001)

Chlorine concentration [Cl] at 0°C and at an altitude of 45 km: mol/L	**Reaction rate (V) in mol/L·s**
$30x10^{-14}$	$1{,}56x10^{-16}$
$48x10^{-14}$	$2{,}50x10^{-16}$
$64x10^{-14}$	$3{,}32x10^{-16}$
$128x10^{-14}$	$6{,}64x10^{-16}$
$384x10^{-14}$	$2{,}00x10^{-15}$

In step 2, the reaction mechanisms and the importance of the slow step of the chemical reaction were discussed, as highlighted in slide number 03 of presentation number 03. Since the equation of the slow step of the reaction was also provided through video dialogue and presented again during classroom discussion, the accepted reaction mechanism step for the kinetic work is: $O_{3(g)} + Cl_{(g)} \rightarrow ClO_{(g)} + O_{2(g)}$ (01).

We can now apply the rate law equation to equation (01) — where we obtained $V = K_1.[O_3]^n.[Cl]^m$ (02) — Also provided in PowerPoint presentation and in a YouTube video as a teaching and learning facilitator (Figure 5):



4- **Concentração dos Reagentes** : Quanto maior a concentração dos reagentes maiores serão os choques das partículas e, portanto será maior a velocidade da reação.

LEI DE VELOCIDADE

Para uma reação genérica :

$$aA + bB \rightarrow cC + dD$$

temos a seguinte expressão da lei de velocidade,

$$V = [A]^x.[B]^y$$

$$\left\{\begin{array}{c} V = \text{Velocidade de Reação} \\ K = \text{Contante de Velocidade} \\ [A] \text{e } [B] = \text{Concentrações molares} \\ x \text{ e } y = \text{Expoentes para serem} \\ \text{determinados experimentalmente} \end{array}\right\}$$

①X e Y são chamadas ordem da reação em relação a cada um dos reagentes.

②A soma dos expoentes(X + Y), é denominada ordem global da reação ou total.

③Reação elementar : É a reação que se processa numa única etapa.

④O conjunto de etapas por meio das quais uma reação se processa é denominado mecanismo da reação e cada etapa é denominada reação elementar.

Prof.: José Pinheiro da Costa Júnior

3ª APRESENTAÇÃO DE CINÉTICA QUÍMICA PARTE 03 1of4

2 visualizações • 7 de fev. de 2021

Figure 5

Video presentations (Júnior, 2023).

In **step 3**, we took the product $K_1.[O_3]^n$ as a new constant called K, since the concentration of O3 is practically constant at a temperature of 0°C and an altitude of 45 km. The new equation then took this form: $V = K.[Cl]^m$ (03).

In **step 4**, we logarithmized on base 10 (this step was meticulously explained to the learners) and multiplied by (-1) on both sides. We needed negative logarithms for formalism reasons. These steps were observed:

First: logarithmize on both sides and apply the properties of logarithms to equation 03:

$$\log V = \log(K.[Cl]^m) \Rightarrow \log V = \log(K.[Cl]^m) \Rightarrow \log V = \log K + \log([Cl]^m)$$

$$\log V = \log K + m\log([Cl]) \quad (04)$$

Second: Multiply equation (04) by (-1):

$$-\log V = -\log K + (-m\log[Cl]) \Rightarrow -\log V = -\log K + m.(-\log[Cl]) \qquad (05)$$

Third: Make a change to:

$$y = -\log V \quad (06); \quad b = -\log K \quad (07) \text{ e } \quad x = -\log[Cl] \quad (08)$$

In **step 5**, we concluded the deduction that indicates the emergence of the slope coefficient m, which will lead us to a first-degree equation of the form, $y = b + mx$ (09), which is interesting and suitable for the learners' understanding.

In **step 6**, we used a scientific calculator on a cellphone, or alternatively, a logarithm table if the teacher wished to delve deeper into Mathematics to make it more significant. We arrived at values on a base 10 logarithmic scale for the data now presented in Table 11, as shown in Table 12.

Table 12.

Logarithmized data of concentration [Cl] and reaction rate (V) (Atkins & Jones, 2001)

x = - log[Cl]	**y = - logV**
12,52	15,80
12,32	15,60
12,20	15,48
11,90	15,18
11,41	14,70

In **step 7**, almost finalizing, the data was plotted on a graph of the type y = - logV on the ordinate and x = - log[Cl] on the abscissa. The same graph was plotted by the teacher using an Excel spreadsheet, as seen in Figure 6:

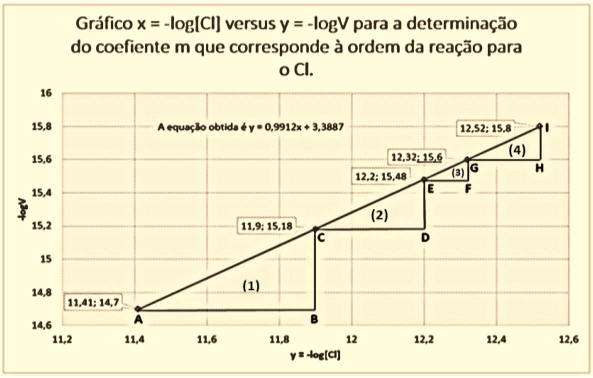


Figure 6

Graph adapted with -log[V] against -log[Cl] obtained using the Excel program from the data in Table 02, showing triangles and can be done with a ruler.

The data from the first-degree equation, with a good approximation margin, were also manually treated in a table by the teacher and the learners' perspective. They indicated the values to the teacher directly from their calculator calculations, finding the average slope coefficient through the values inherent in the graph from triangles A, B, C, and D, according to Table 13:

Table 13.

Values obtained by the sides of triangles 1,2,3, and 4 and their respective tangents mathematically equal to the orders of reaction of the ozone layer degradation reaction and by approximation to integer numbers

Triangles	**Measurement of the sides AB, CD, EF, and GH respectively.**	**Measurement of the sides BC, DE, FG, and HI respectively**	Ratios between the opposite side and the adjacent side, which is equal to **tan(α) = m.**
In triangle (1)	11,90 – 11,41 = 0,49	15,18 – 14,70 = 0,48	0,48/0,49 = 0,979
In triangle (2)	12,20 – 11,90 = 0,30	15,48 – 15,18 = 0,30	0,30/0,30 = 1,000
In triangle	12,32 – 12,20 =0,12	15,60 – 15,48 = 0,12	0,12/0,12 = 1,000

(3)			
In triangle (4)	12,52 – 12,32 = 0,20	15,80 – 15,60 = 0,20	0,20/0,20 = 1,000

The obtained values lead to an arithmetic mean M=(0.979+1+1+1)=0.994, which is very close to the value obtained in Excel of 0.9912, which works with the linear regression model, which we did not work with in this article because it is too complex. We also observe a great proximity to the experimental value of the reaction order of this experiment, which is 1, which demanded a very appropriate transposition from wise knowledge to taught knowledge. This value of 1 indicates that, in the act of chlorine atoms attacking ozone, only one chlorine atom is needed to start a reaction and pave the way for other chlorine atoms. This clearly demonstrates that, through the use of modeling, learning for the learners is favored

The equation $V = K_1.[O_3]^n.[Cl]^m$, then becomes:

$$V = K_1.[O_3]^n.[Cl]^1 \quad (10)$$

In **step 8**, with this equation, which is the equation or rate law of the studied reaction, it is sufficient to substitute the values from Table 1 and the value of K1 = $6{,}49\text{x}10^6$ mol/L.s to find the exponent that corresponds to the reaction order with respect to O3. We could use any of the rows from Table 11; however, let's use the row corresponding to the first set of data to substitute into $V = K_1.[O_3]^n.[Cl]^1$. Thus, we have:

$$1{,}56\text{x}10^{-16} = 6{,}49\text{x}10^6.(8\text{x}10^{-11})^n.(30\text{x}10^{-14})^1 \Rightarrow (8\text{x}10^{-11})^n = 1{,}56\text{x}10^{-16}/194{,}7\text{x}10^{-8}$$

$$(8\text{x}10^{-11})^n = 8\text{x}10^{-11}$$

$$\text{Logo, } n = 1$$

This leads to the final equation:

$$V = K_1.[O_3]^1.[Cl]^1 \quad (11)$$

Finally, we have **step 9**, **which is interpreting the obtained equation**. The values found for m and n indicate that if m = 1 and n = 1, only one molecule of each reactant is required for the degradation of ozone to begin, meaning it is a 1-to-1 relationship and first-order for each participant in the reaction. The overall order of the reaction corresponds to the sum of the exponents, which is 2.

Now, the completion of task (T06) for the teacher and task (T04) for the learners, which corresponds to a proposal for a simple and inexpensive experimental activity with presentation of resolution by one of the teams.

As the ozone decomposition reaction is difficult to carry out in basic teaching laboratories, or even in college labs with limited reagents and equipment, we opted for another much simpler reaction to be performed. Since we had already discussed environmental issues promoting STS education and established mathematical and chemical understanding of the determination of reaction orders and the rate equation, which is our main focus. The practical example that best suited the teaching proposal and that can be useful for teacher training and enhancing student learning in the development of skills and competencies was the application of a chemical reaction in a new context, which demonstrates that kinetic data can be constructed without magic and treated mathematically.

In this set of tasks (t) for both the teacher and the learners, we identified the technologies (θ) **Vernacular Language** or **Portuguese Language**, **Chemical Symbolism**, and **Experimental Procedures**, and the Theories (Θ) **Kinetics of Chemical Reactions**, Analytical Chemistry, treated in the subsunctors **Solutions** and **Reaction Stoichiometry**. The reaction involved sodium thiosulfate pentahydrate and hydrochloric acid found in supermarkets, which react according to the equation:

$$\underbrace{S_2O_3{}^{-2}{}_{(aq)}}_{\text{TIOSSULFATO}} + \underbrace{2H^+{}_{(aq)}}_{\text{ÁCIDO}} \rightarrow \underbrace{SO_{2(g)}}_{\text{DIÓXIDO DE ENXOFRE}} + \underbrace{H_2O_{(l)}}_{\text{ÁGUA}} + \underbrace{S_{(S)}}_{\text{ENXOFRE(turvador)}} \qquad (12)$$

The reaction was carried out and recorded during three Chemistry classes in the interdisciplinary laboratory of IFPA, Abaetetuba Campus, by students from the second year of technical and integrated education in MSI, Informatics, and Building Construction courses, in 2023, under the guidance of one of the professors involved in this research. We emphasize that this activity does not require modern and expensive technological apparatus. The experimental procedure is described in the next section and followed basic safety measures.

Objectives of the experimental procedure:

1) In this experiment, the objective is to determine the reaction order between HCl and $Na_2S_2O_3.5H_2O$ in solution by observing the turbidity caused by solid sulfur (S) using the method previously discussed for ozone layer degradation (Figure 7). As materials and reagents, we have: 3 schematics to provide guidance as shown in Figure 7:

Figure 7.

Laminated schematics to support the reaction

2) Table of composition of moles of reagents used and their molar concentrations already presenting the results of time obtained from the experimental videos (Figure 8):

Experimentos	$[H^+]$(mol/L)(Ácido muriático)	$[S_2O_3^{-2}]$ (mol/L) e -log$[S_2O_3^{-2}]$	t(m) do experimento
①	50 mL de solução C mols/L de ácido muriático (retirada direto do frasco do ácido de supermercado sem modificações)	0,290120 mol/L e -log0,290120 = 0,53743	≅ 12,40 s
②	50 mL de solução C mols/L de ácido muriático (retirada direto do frasco do ácido de supermercado sem modificações)	0, 1450560 mol/L e -log0,1450560 = 0,838464	≅ 23,40 s
③	25 mL de solução C mols/L de ácido muriático (retirada direto do frasco do ácido de supermercado sem modificações) e acrecentar 25 mL de água destilada em fica $[H^+]$ = C/2	0,1450560 mol/L e -log0,1450560 = 0,838464	≅ 24,20 s

Tarefa: Plotar (–logV) contra (–log[X]) para $[S_2O_3^{-2}]$ e $[H^+]$

Figure 8.

Table of compositions of solutions, reaction time, and their logarithms

3) 2 graduated cylinders or equivalent containers with a capacity of up to 50 mL preferably.

4) 2 or 3 100 mL beakers.

5) Solutions of HCl (supermarket hydrochloric acid without needing to know the concentration and taken as C and C/2). We remind that the only task in producing the concentration C/2 is to dilute 25 mL of the original acid with 25 mL of distilled water, according to Table x, which presents the cross schemes. This acidic solution can be found in car product stores.

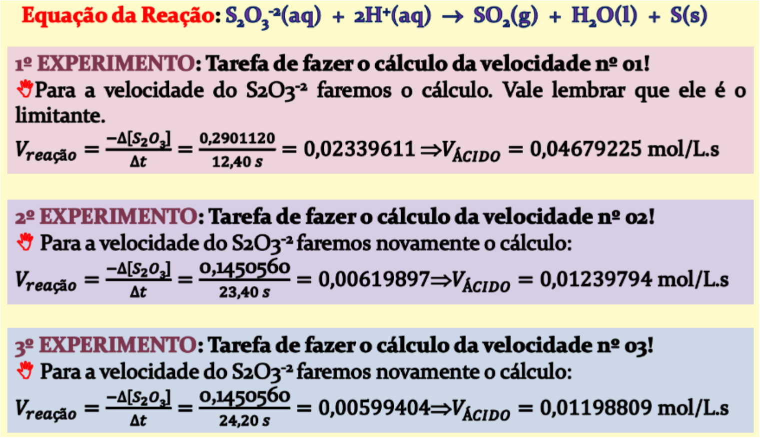
6) Solutions of $Na_2S_2O_3.5H_2O$ prepared on-site with specified masses and molarities, as shown in Figure 7.

7) 1 liter bottle of distilled water.

8) 1 digital stopwatch (we can use the students' or teacher's cell phone) to detect the disappearance of the cross (+) under the beaker with the mixture of acid and sodium thiosulfate pentahydrate, as described in item 3.1.4, with all procedures involving the reactions described in video.

Calculation of reaction rates post-experimental activity

In this final set of tasks (T), there was a careful observation of the experimental videos. Thus, we established Task (t14) for the teacher to engage in dialogue with the learners (Figure 9).



Equação da Reação: $S_2O_3^{-2}(aq) + 2H^+(aq) \rightarrow SO_2(g) + H_2O(l) + S(s)$

1º EXPERIMENTO: Tarefa de fazer o cálculo da velocidade nº 01!

Para a velocidade do $S_2O_3^{-2}$ faremos o cálculo. Vale lembrar que ele é o limitante.

$$V_{reação} = \frac{-\Delta[S_2O_3]}{\Delta t} = \frac{0{,}2901120}{12{,}40\ s} = 0{,}02339611 \Rightarrow V_{ÁCIDO} = 0{,}04679225\ \text{mol/L.s}$$

2º EXPERIMENTO: Tarefa de fazer o cálculo da velocidade nº 02!

Para a velocidade do $S_2O_3^{-2}$ faremos novamente o cálculo:

$$V_{reação} = \frac{-\Delta[S_2O_3]}{\Delta t} = \frac{0{,}1450560}{23{,}40\ s} = 0{,}00619897 \Rightarrow V_{ÁCIDO} = 0{,}01239794\ \text{mol/L.s}$$

3º EXPERIMENTO: Tarefa de fazer o cálculo da velocidade nº 03!

Para a velocidade do $S_2O_3^{-2}$ faremos novamente o cálculo:

$$V_{reação} = \frac{-\Delta[S_2O_3]}{\Delta t} = \frac{0{,}1450560}{24{,}20\ s} = 0{,}00599404 \Rightarrow V_{ÁCIDO} = 0{,}01198809\ \text{mol/L.s}$$

Figure 9.

Kinetic calculations

In this case, there is no need to use the methodology for determining the reaction order with respect to the acid, as the time in the last two experiments is practically the same. Therefore, the slope for the experiments with respect to H^+ is approximately zero (0). Taking again equation (12), represented by:

$$\underbrace{S_2O_3{}^{-2}{}_{(aq)}}_{\text{TIOSSULFATE}} + \underbrace{2H^+{}_{(aq)}}_{\text{ÁCID}} \rightarrow \underbrace{SO_{2\,(g)}}_{\text{DIÓXIDO DE ENXOFRE}} + \underbrace{H_2O_{(l)}}_{\text{WATER}} + \underbrace{S_{(S)}}_{\text{ENXOFRE(turvador)}}$$

We can infer the following rate equation:

$$V = K_1.[S_2O_3{}^{-2}]^1.[H^+]^0 \qquad (13)$$

This clearly demonstrates that stoichiometric coefficients do not always correspond to reaction orders.

Results and discussions

The evaluation of our educational path highlighted that Chemical Kinetics, despite being a highly abstract subject due to its physical-chemical and mathematical formalisms, can be taught through a deep investigation of academic knowledge and effective didactic transpositions. This content can be transmitted using alternative methodologies to discover reaction orders, based on real environmental issues, such as ozone layer degradation, according to the STS approach. Additionally, we have the recourse to an alternative mathematical treatment. It fundamentally relies on the use of triangles and tangents, which can assist in determining reaction orders, as evidenced by the calculations presented by the second-year MSI students.

In their work, the students, along with those from other involved classes, used approximate values of 12.5s, 25s, and 25s. This did not compromise teaching and learning or the reliability of the scientific methodology, demonstrating that it is possible to approach complex topics in an accessible and effective manner.

Action research promoted teacher protagonism in the search for teaching facilitators from the perspective of conducting activities with simple materials and techniques, and student protagonism in researching technologies (θ) and theories (Θ) based on techniques (τ), as demonstrated by the elaboration of refined and well-written calculations on the Canva website, which is a free presentation, video, and post design tool as shown in Figures 10 and 11.

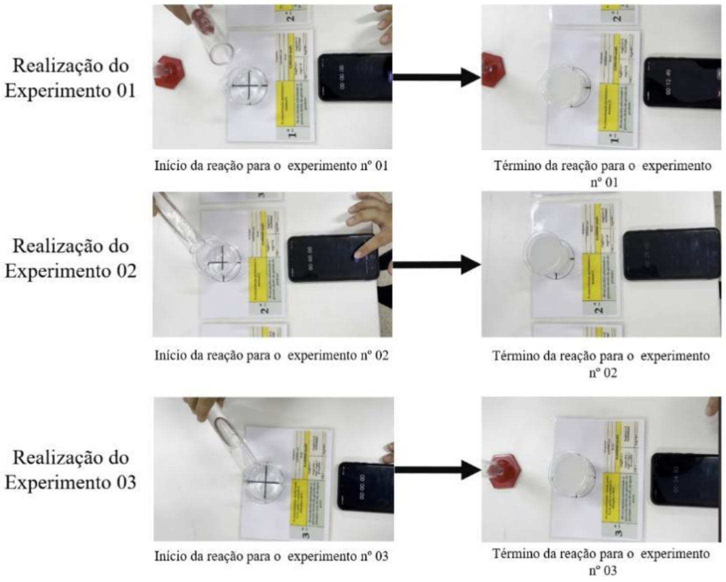


Figure 10.

Chemical reactions with approximate measured reaction times

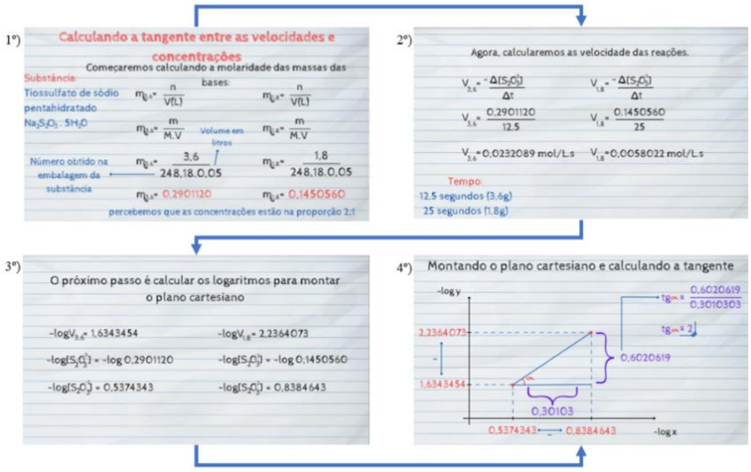


Figure 11.

Kinetic calculations (Elaborated by the 2nd-year MSI students)

Therefore, the act of knowing-how inherent in the duet task-technique is corroborated by Freire's statement (2002): "Knowing how to teach is not transferring knowledge, but creating the possibilities for its own production or construction" (p. 37).

Final considerations

The evaluation and self-assessment of the work revealed a significant articulation between students' daily lives and the content taught, as well as interdisciplinary connections between Mathematics and Chemistry. This connection proved essential for the understanding of Natural Sciences and was extremely valuable for student learning.

It was possible to observe that gaps in understanding and use of concepts such as Cartesian graphs, logarithms, algebraic calculations, use of scientific calculators, basic trigonometry, and even work with exponential equations were filled. These results reinforce the idea of the Anthropological Theory of Didactics (TAD), which emphasizes the importance of connecting scientific knowledge with students' everyday knowledge in order to provide more meaningful learning experiences.

Furthermore, the adoption of a diagnostic, continuous, and procedural teaching approach, which brings topics to "life" and carries out appropriate didactic transpositions, highlights the relevance of the "didactic contract" of TAD. This confirms the idea that students value teachers who not only possess teaching skills, clarity, and good classroom management, but also show interest in their students, are supportive, friendly, and respect their feelings (Hart, 1934; Leeds, 1954 cited in Ausubel, 1980, p. 420). This aspect aligns with the praxeological dimension of TAD, which refers to the relationship between theoretical knowledge and social practices in the educational environment.

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