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ARTICLE

BETWEEN NORMS AND ROUTINES OF ORGANIC CHEMISTRY: THE WORK WITH THE DOMAINS OF SCIENTIFIC KNOWLEDGE

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ABSTRACT:

We assume that the approximation of norms and routines characteristic of scientific activity can be an element that promotes science learning. Thus, we aim to answer the research question: “In Organic Chemistry classes for Higher Education students, which domains of scientific knowledge are mobilized by the professor?”. Therefore, Organic Chemistry classes in a teacher training program in Chemistry were recorded in audio and video. The data produced for this research come from the transcription of these recordings and were analyzed qualitatively in order to identify mobilization of the domains of scientific knowledge by the professor. The results indicated that the conceptual and material domains appear frequently, and the epistemic rarely. The social domain, on the other hand, appears linked to the use of representations. When interacting with these domains, the professor relates the experimental material to the use of representations. As implications of this research, we defend the idea of an epistemic object to approach visual representations and characterize the material domain.

Keywords:
Higher Education;
Social domain;
Material domain.

ENTRE NORMAS Y RUTINAS DE LA QUÍMICA ORGÁNICA: EL TRABAJO CON LOS DOMINIOS DEL CONOCIMIENTO CIENTÍFICO

RESUMEN:

Partimos del supuesto de que la aproximación a normas y rutinas propias de la actividad científica puede ser un elemento que promueva el aprendizaje de las ciencias. Así, buscamos responder a la pregunta de investigación: “En las clases de Química Orgánica para estudiantes de la educación superior, ¿qué dominios del conocimiento científico son movilizados por el docente?”. Para ello se grabaron clases de Química Orgánica, en audio y video, para una clase de grado en Profesorado en Química. Los datos producidos para esta investigación provienen de la transcripción de esas grabaciones y fueron analizados cualitativamente con el objetivo de identificar la movilización de los dominios del conocimiento científico por parte del docente. Los resultados indican que los dominios conceptual y material aparecen con frecuencia, y el epistémico rara vez. El dominio social, en cambio, aparece ligado al uso de las representaciones. Al interactuar con estos dominios, el docente relaciona el material experimental con el uso de representaciones. Como implicaciones de esta investigación defendemos la idea de un objeto epistémico para acercarnos a las representaciones y caracterizar el dominio material.

Palabras clave:
Educación Superior;
Dominio social;
Dominio material.

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ENTRE NORMAS E ROTINAS DA QUÍMICA ORGÂNICA: O TRABALHO COM OS DOMÍNIOS DO CONHECIMENTO CIENTÍFICO

RESUMO:

Partimos do pressuposto de que a aproximação de normas e rotinas características da atividade científica pode ser elemento promotor de aprendizagem das ciências. Assim, buscamos responder a questão de pesquisa: "Em aulas de Química Orgânica para estudantes do ensino superior, quais domínios do conhecimento científico são mobilizados pela professora?" Para isso, foram gravadas, em áudio e vídeo, aulas da disciplina de Química Orgânica para uma turma de Licenciatura em Química. Os dados produzidos para esta pesquisa advêm da transcrição dessas gravações e foram analisados qualitativamente com o objetivo de identificar a mobilização dos domínios do conhecimento científico pela professora. Os resultados indicaram que os domínios conceitual e material surgem com frequência, e o epistêmico raramente. Já o domínio social surge vinculado, especialmente, ao uso das representações. Ao interagir com esses domínios a professora relaciona o material experimental ao uso das representações. Como implicações desta pesquisa defendemos a ideia de objeto epistêmico para abordagem das representações e caracterização do domínio material.

Palavras-chave:
Ensino Superior;
Domínio social;
Domínio material.

INTRODUCTION

The studies in the history, philosophy, and sociology of science support the idea that scientific activity is social, especially considering that the members of the scientific community negotiate with one another to produce theories, understand phenomena, and interact with natural processes conducted by norms, routines, and values (Knorr-Cetina, 1999; Longino, 1990; 2002; Pickering, 1995). Based on these ideas, several researchers in Science Education defend the need to encourage interactions between students and teachers with materials and knowledge, considering norms and practices characteristic of scientific activity, as elements to promote science learning (Deng *et. al*, 2019; Duschl, 2008; Franco & Munford, 2020a; Sasseron, 2021; Stroupe, 2014).

When considering the construction of understandings in the classroom via social interactions, the conception of science teaching as a social practice is only sustained when the domains of scientific knowledge are mobilized (Silva *et. al*, 2022). This is because the understanding of knowledge in the classroom does not only occur by having contact with concepts, theories, principles, laws, definitions, and ways of reasoning scientifically (conceptual domain). This understanding also involves participation within this school community which, by using and constructing understandings concrete and abstract materials (material domain), negotiating and reproducing norms, routines, and values (social domain) to determine the way these understandings are proposed, communicated, evaluated, and legitimized (epistemic domain) (Duschl, 2008; Kelly & Licona, 2018; Stroupe, 2014).

The discussion about the incorporation and integration of conceptual, epistemic, social (Duschl, 2008) and material (Stroupe, 2014) domains for learning processes in science classes has stimulated several research in the area of Science Education with different objectives. For instance, there are studies that: i) emphasize the comparison of the predominance of specific domains mobilized by scientists, science teachers, and elementary school students (Peters-Burton & Baynard, 2013), ii) aim at the implementation of classes that propose the integration between the domains and processes of investigative approaches (Papadouris & Constantinou, 2014; Van Uum *et al.*, 2016; 2017), iii) provides implications for the pedagogical content knowledge of science teachers from this integration (Van Uum *et al*., 2019), and iv) promotes the understanding of practices developed by students from the articulation between domains (Franco & Munford, 2020a,b; Kim & Tan, 2013; Sasseron, 2021).

In general, there is a consensus among the researchers of the aforementioned studies that the domains of scientific knowledge are interdependent, and therefore there is a need for them to be articulated for science learning (Duschl, 2008; Franco & Munford, 2020b; Stroupe, 2014; Sasseron, 2021). For example, Franco and Munford (2020b) defend that the conjunction of epistemic and social confers an investigative character to classes, contributing to the development of practices closer to scientific ones by students.

Furthermore, three observations can be highlighted: i) the material domain of scientific knowledge has yet to be thoroughly investigated, ii) the understanding of the social domain still needs to be further explored for what it really means. In the other words, about how teachers and students interact and understand norms and routines typical of scientific activity to communicate, discuss, and develop ideas, as proposed by Duschl (2008) and Stroupe (2014), and iii) a lack of studies on the subject in Higher Education classes. The last two observations instigated the development of this research.

Thus, in this paper we aim to answer the following research question: "In Organic Chemistry classes for Higher Education students, which domains of scientific knowledge are mobilized by the professor?" For this purpose, we analyze how these domains appear in Organic Chemistry classes of a public university, which part of the teacher training program for Chemistry. For the study, we understand that it is necessary to turn our attention not only to studies already carried out in Science Education, but also to studies on science and Organic Chemistry, since the analysis of norms, routines, and values that arise in the classroom, should not be restricted to characteristics of school culture when we aim to explain and develop cultural characteristics of science.

THE PRODUCTION OF SCIENTIFIC KNOWLEDGE IN THE LABORATORIES

Analyzing the production of scientific knowledge, Knorr-Cetina (1999) shows that, in the laboratory, scientists rarely work with the object of study as it is found in nature. The researcher state that there are three features of a natural object that the laboratory does not have to accommodate: i) as it is, since the natural object in the laboratory can be replaced by partial and transformed versions, ii) where it is, since it can be manipulated under laboratory conditions, and iii) when it happens, since the natural cycle of occurrence of the natural object can be dispensed, interfering even its frequency. We can also include a fourth feature: what purpose it serves, because the function of this natural object can be changed.

Hence, the laboratory allows the objects to be moved from their natural environment to another environment defined by a social agency (Knorr-Cetina, 1999; Pickering, 1995). Pickering (1995) reminds us, however, that social agency can be understood as the aggregation and recomposition of human and material agencies. In other words, in social agency, the scientific activity is human, also occurring with access to materials, intertwining in an effort to understand and interact with the world.

The production, evaluation, and legitimation of scientific knowledge are configured from and with the interests and limitations of human agents, thus indicating that there is a human agency (Pickering, 1995). According to the author, this agency is not unconnected from materiality, e.g., we respond to storms and cold by building houses and clothes, and, in the absence of materials and instruments for this purpose, our lives would be at risk. From this example, he suggests that the production, evaluation, and legitimation of scientific knowledge also involves the materiality available when scientific activity is taking place. Therefore, he proposed that there is a material agency that intertwines with human agency. For this author, the contours of material action are not previously defined, since scientists need to constantly explore them in their activities, because of the emergence and resolution of problems in the development of scientific knowledge.

Pickering (1995) recognizes the importance of social relationships and human skills for the production of knowledge but understands that they are not enough for the development of scientific activity. According to him, the knowledge, while constructed from material agency – i.e., from the concrete and abstract materials that are available at that moment – is mediated by human agency and the mental constructions, practices, and social relations that allow access to these materials. The inclusion of abstract materials for Pickering is justified by the fact that materiality is not constituted only by concrete materials that perform a physical action but also includes the representations that permeate scientific activity, moving these processes of knowledge production. We understand that representations can assume materiality if we problematized their uses and their consequences in the process of knowledge production and development in science. Thus, we did not intend to analyze our data based only on language studies, which guide research on multimodality, although we recognize their importance.

From these ideas, we agree with Knorr-Cetina (1999) in proposing that the laboratory is not restricted to the place where the experiments are carried out since it brings together the different subjects who transit there, the relationships and social norms that are established and negotiated dialectically in the laboratory, the objects of study that diversify in temporality, and the various types of devices, instruments, equipment, materials, files, and representations that consolidate the work of subjects from different fields of knowledge, promoting varied cultural, social, and technical postures.

CONSIDERATIONS ON THE FEATURES OF ORGANIC CHEMISTRY

In this study, we briefly present the characterization of Organic Chemistry as a sub-area of Chemistry, with norms, routines, and values that are permeated by material, conceptual, and representational contexts (Goodwin, 2003; Hoffman & Laszlo, 1991; Laszlo, 1998).

In Chemistry, the substances are extracted and purified from natural sources and/or are designed and produced in the laboratory, on both small and large scales, while their properties are described and inferred in representations in papers (Jacob, 2001). Thus, the materials used to produce these compounds in the laboratory, as well as the norms and conceptual aspects associated with representations, which allow expressing physical and chemical properties, are central to the construction of chemical knowledge. According to Hoffmann and Laszlo (1991), beakers and distillation columns, as well as the structural formulas, are hallmarks of Chemistry since the laboratory becomes the locus of a symbolic work on matter by accommodating its transformations, production of concepts, and representations (Laszlo, 1998).

In general, in Organic Chemistry, the interaction with a phenomenon is not accommodated by a single law, as in Physical Chemistry, but by a complex network of theories, concepts, and representations that constitute what Goodwin (2008; 2010) calls structural theory. For Goodwin (2003), Organic Chemistry is where the organic molecules and their reactions are studied, involving aspects related to energy, speed, and the routes that lead to the products arising from these reactions. Goodwin (2010) understands structural theory not as a fixed set of statements in the traditional philosophical sense, but as an approximation to a methodological strategy for the elaboration of predictions and explanations of the properties and transformations of organic compounds, based mainly on the structural formula. In our interpretation, when highlighting the structural formula, the author does not separate it from the conceptual aspects necessary for the construction of knowledge in Organic Chemistry, but they highlight the centrality of these representations. Similarly, Statham (2017), when referring to the concepts of nucleophile and electrophile, shows that chemists can predict their use in a nucleophilic substitution reaction from the structural formulas of chloride, bromide, and hydroxide, and see that the nitronium ion is not used. In summary, structural formulas allow organic chemists to categorize chemical species and predict the reactions that groups of these species may suffer (Goodwin 2012; Statham, 2017).

Goodwin (2010), when showing the centrality of representations in Organic Chemistry, argues that they are not abandoned with each new empirical evidence (e.g., dipole moment measurements) and/or theoretical development (e.g., theory of molecular orbitals). In our interpretation, the author understands that the development of the theory of molecular orbitals occurred in a historical process that changed the forms of representation and their own structural theory. However, he highlights, as an example, that the structural formula for water, written as H-O-H, has not been replaced by a representation involving orbitals since it continues to be used in some contexts. We recognize that this form of representation has limitations, and the fact of using one form or another is related to the norms that govern its use and interpretation in a specific situation. In this sense, Organic Chemistry is defined by a specific system of representations developed over time, conventionalized (Hoffmann & Laszlo, 1991) and situated.

EXPLORING THE SOCIAL DOMAIN OF SCIENTIFIC KNOWLEDGE IN THE CLASSROOM

For the contact of students with the different domains of scientific knowledge, Duschl (2008) defends the incorporation of dialogic processes of knowledge construction in science learning, which would allow students to develop practices that promote the understanding of how they know what to know, and why they are believed they know it. Thus, he emphasizes that these practices cannot be merely manipulative and without intellectual involvement, which would only result in the execution of a guide with defined steps. In this perspective, Duschl (2008) proposes three domains of knowledge that should emerge in an integrated way within classroom approaches and in the assessment of science learning: the conceptual, which are "structures and cognitive processes used when reasoning scientifically"; the epistemic, which are "frameworks used when developing and evaluating scientific knowledge"; and the social which are "processes and contexts that shape how knowledge is communicated, represented, argued, and debated" (p. 277).

Considering the ideas of Lehrer and Schauble (2006) on teaching science as practice and of Duschl (2008) on the domains of scientific knowledge in the classroom, for Stroupe (2014; 2015) the dimensions of work discipline to learn science as practice include a fourth domain, the material. The inclusion of the material domain of scientific knowledge by Stroupe (2014) shows that materials, tools, and resources can carry an epistemic role in the classroom since they are not just accessories. Stroupe (2014) proposes this domain supported by the ideas of Pickering (1995), in which the objectives of scientific activity also occur at the moment that it is happening and, therefore, this knowledge is produced from the materials that are available at that time, as discussed previously. In this perspective, Stroupe (2014), defending a more authentic approach to science in the classroom, indicates that students need to experience activities that involve unpredictability, reasoning, and transformation of ideas, which are supported by the use with intellectual involvement of tools, technologies, and resources.

The social domain of scientific knowledge has been perceived as communication and collaboration to solve problems based on an established consensus in the group (Kim & Tan, 2013), collaboration and research presentation (Van Uum *et al*., 2016; 2017; 2019), communication and negotiation of observations, collective construction of work routines and data-based conclusions, peer disagreement, consideration and articulation of teacher and peer ideas during discussions (Franco & Munford, 2020a,b), and agreed norms that are followed by the students in the group to conduct the proposed activities (Sasseron, 2021). We can infer that the collective work by students and teachers has been the understanding about the social domain common to all authors mentioned previously. We agree with the ideas expressed by them, but we understand that this domain of scientific knowledge is not limited to the collectivity allowed by group work, but by the spaces of criticism that are created, contributing for the negotiation and/or reproduction of norms, values, and routines that promote the development of school activities.

These norms and routines are still underexplored in the studies found in the Science Education literature, as mentioned previously. In this sense, we seek the study of Longino (1990), philosopher of science, as a theoretical support for understanding the social domain. Longino (1990, 2002), when discussing the social character of scientific knowledge, conceives scientific activity governed by norms and values because it consists of different practices performed by different people and/or research groups that negotiate to produce theories, understand phenomena, and interact with natural processes, etc. She defends that the cognitive practices of science have a social dimension necessary for the recognition of what knowledge claims, shaping and being shaped by a wider context. Longino (1990) discusses the need for this social dimension, exposing the three aspects of the social nature of science proposed by Grene (1985): i) science is practiced by social groups and is linked to norms, practices, and resources, thus considered a social enterprise; ii) to become a practitioner and belong to these groups, there is a need for initiation, learning from those who are already practitioners and who belong, to know, reproduce, and negotiate these norms, practices, and resources; and iii) the practice of these individuals become the practice of a community immersed in a society that also has norms and values.

Based on these ideas, Longino (2002) proposes four social norms of social knowledge: the existence of *venues*, the establishment of *public standards* of analysis, *uptake* to criticism, and the constitution of *temperate equality*. The existence of *venues* consists of the spaces indicated for the discussion and criticism of the ideas proposed by practitioners of scientific activity, and both the proposition and the evaluation of the ideas have the same value. For her, these spaces can be, e.g., scientific meetings and papers. The establishment of *public standards* of analysis are the criteria defined in and by the community of practitioners for evaluating ideas, that is, they allow assessing whether the proposed ideas are appropriate to the field of knowledge. However, according to the researcher, these standards are not limiting, but necessary for criticism to occur responsibly and allow its understanding by all members of the community. She also points out that these standards are not immutable, but that they can be transformed in and by the community. The *uptake* to criticism means participating in the critical discourse that takes place within the community, which involves considering the criticism that has been made. However, she defends that the term considers not only agreeing but also discussing, modifying when necessary, and evolving. The constitution of *temperate equality* means all members of this community are considered capable of proposing and evaluating ideas, if they conform to the norms established by this community.

The ideas discussed expose our perception that the social domain is not characterized only by collaboration, discussion, and communication, that is, only when carrying out activities in groups. This collective moment needs to be critical, not limited to the proposition of ideas but extrapolative for their evaluation. However, this evaluation does not occur randomly (e.g., refuting a colleague's idea due to personal reasons), but adjusting to the norms and routines of the field of knowledge. We are not defending that students behave like scientists, but that, in the classroom, some features of the field of knowledge remain. The students, when their ideas are evaluated, can agree with the criticisms and modify their ideas, but they can also disagree, as long as they are adequate when responding to these criticisms. The teacher, when carrying out this articulation, distributes the epistemic authority with the students, constituting a moderate equality, in which students also have legitimacy to propose and debate ideas.

METHODOLOGICAL ASPECTS

In Organic Chemistry classes for Higher Education students, which domains of scientific knowledge are mobilized by the professor? To address this research question, we aim to analyze how these domains occur in Organic Chemistry classes. The characterization of the domains of scientific knowledge has been challenging (Franco & Munford, 2020a;b; Peters-Burton & Baynard, 2013), because in many situations they are interdependent and can occur in pairs, triplets or all together (Franco & Munford, 2020b).

We adopted a qualitative approach to analyze the professor's interaction with the domains of scientific knowledge in the classroom, because this approach has its basis in the dynamic relationship between the real world and the different subjects, allowing a detailed description of contexts, situations, people, interactions, behaviors, and speeches of the subjects (Lüdke & André, 2013). The reported paper is a research focus on professor from a broader project. Therefore, it is a case study in which we analyze the emergence of the scientific knowledge domains in the classroom during the professor's speeches, preserving the situations of their context (Yin, 2001).

The classes and the data under analysis

We analyzed the initial classes of Organic Chemistry II, at a public university. The course was conducted in the classroom, and not in the laboratory. This information is necessary because the professor often relates what occurs in the laboratory to build the reaction mechanisms proposed to the chemical reactions studied in this course. To collect data for classroom observations, we chose to record these classes in audio and video because we understand that the professor's discursive interactions with the students are opportune moments for the characterization of the domains of scientific knowledge. The classes occurred in March 2020 and the course was interrupted due to the health measures imposed by the COVID-19 pandemic. Thus, the data of this study corresponds to the recording of two classes with 100 minutes each. The professor and participating students of the course signed the Informed Consent Form accepting participation in the collection of information for use in this research. To ensure the preservation of their identities, pseudonyms are used for students, and we will not name the professor.

The Organic Chemistry II course is offered in the fourth academic period within the teacher training program in Chemistry and has as a prerequisite of Organic Chemistry I course. In the course, the reactions involving organic compounds and structural characterization methods are studied, such as infrared absorption spectroscopy, mass spectrometry, and nuclear magnetic resonance. The Organic Chemistry courses were divided into theoretical and practical, and the practical part, called Experimental Organic Chemistry, will only be offered when students are in the fifth academic period. The Organic Chemistry II course was chosen because it features the use of visual representations that allow understanding norms, routines, and values of both of the scientific community and of the classroom.

The professor was chosen because of her 29 years of experience as a Higher Education professor, of which 16 years were at the university where the classes were recorded. Additionally, she supervises dissertations and theses within her department's postgraduate program, and since joining the institution, she has been researching the chemistry of natural products. This information indicates that she is an experienced professor and researcher who is part of a scientific community, which has norms, routines, and values (Longino, 1990). Another reason for her choice was the fact that her classes had already been analyzed by researchers in Education from the institution itself, and, therefore, we understand that she may feel comfortable with the presence of researchers and the recording equipment in the classroom.

In the classes recorded for this study, the professor reviewed concepts already studied by students in the Organic Chemistry I course, emphasizing resonance structures and reaction mechanisms. She also discussed the obtaining reactions of alcohols and ethers, and those they can undergo. For this discussion, the professor used issues I and II of the Organic Chemistry textbooks (Solomons & Fryhle, 2002) and slides containing a variety of representations, among which we highlight chemical structures and equations, mechanisms, some examples of reactions, definitions, and questions for students to respond. In general, some questions were solved in the classroom and others the professor encouraged students to respond at home. In addition to projecting the slides, the professor constantly used the board to build chemical structures and reaction mechanisms. When students were solving questions in the classroom, the professor would walk, observing and intervening in the resolution if necessary. The professor questioned the students, but only three students participated more actively in these discussions. In an attempt to involve the other students in the discussion, she would indicate students to answer the question. In some situations, she would ask the nominated students to go to the board to do the reaction mechanisms. In this context, when we analyze the professor's speeches, we can identify whether the domains of scientific knowledge emerge, and the way in which they occur allows us to understand how the mobilization of norms and routines occurs during her classes. Therefore, only the professor's speeches were categorized according to the domains of scientific knowledge.

The data were collected from notes in a logbook and from video and audio recordings of the classroom. For video recording, two video cameras were used, one of them fixed and positioned in front of the classroom, close to the professor's desk, focusing on her, and the second video camera was mobile, handled by one of the researchers of this study who also stayed in front of the classroom. For the data obtained in audio, five audio recorders were spread around the room, one of which was fixed on the professor's desk. The data analyzed in this paper were produced from the transcripts of the audio and video recordings and represent the discursive interactions that occurred during the classes, as well as the notes taken in the logbook. We did not interfere in the teaching and learning process, because we sought to follow how these interactions occurred in the professor's natural environment (Carvalho, 2011) so that students could understand the themes and processes of Organic Chemistry.

The transcriptions of the speeches were made in full and organized in a table in which each line was designated as a turn of speech of a subject, obeying the norms indicated to represent speech intonations, pauses, among others (Carvalho, 2011) – e.g., [...] to indicate that an excerpt was omitted in the turn of speech, ... to indicate any type of pause, (()) to indicate insertion of comments, (___) to indicate overlapping speech, and / to indicate word confusion. According to Carvalho (2011), the episodes are excerpts from the transcripts that show the situation we intend to investigate; in our research, these refer to situations in which the domains of scientific knowledge in the classroom were mobilized by the professor. We organized the transcripts of the two classes into eight episodes, but in this article we describe only those that indicated evidence for the characterization of the different domains: i) resumption of the discussion on the physical properties of alcohols, ii) resumption of the discussion on the reactions for obtaining alcohols, iii) discussion of the reactions that alcohols can undergo, and iv) discussion on the reactions to obtaining the ethers.

The categorization of scientific knowledge domains (Duschl, 2008; Stroupe, 2014) in the professor's speech turns were carried out according to Table 1. The students' speech turns were not characterized, because we focus on analyzing the professor's mobilization of different domains of scientific knowledge in the Organic Chemistry classes.

Table 1. Demonstration of the categorization carried out in the teacher's speaking turns, involving the episode about reactions to obtaining alcohol[1]

Domains	Descriptions	Example	Comments
Material	*Support* for explanations based on the use, creation and adaptation of materials, resources, and technologies.	[...] if we use BH3 in the presence of THF... Then the other flask... can't be together... oxygenated water and OH...	The indication that the reagents must be used in a certain order sustain the explanation for the formation of alcohol.
Conceptual	*Exposure* of concepts, theories, laws, and ideas.	[...] we are going to obtain alcohol...	Exposes the functional group of the compound produced.
Epistemic	*Explanation* of the reasons that led to the exposition of concepts, theories, laws, and ideas.	[...] where the hydroxyl will enter the least substituted or most free carbon... less hindered...	Explains the reason for the formation of alcohol, from the bonding of the hydroxyl group on the carbon atom bonded to more hydrogen atoms.
Social	*Establishment* of norms, routines, and agreements used to build understandings in the classroom.	[...] After... you do make the right mechanism... arrow by arrow... to show the formation of these products.... Is it agreed? [...]	Although the construction of the mechanism is associated with the conceptual domain, by reinforcing the use of arrow by arrow the professor establishes a norm, according to Longino (2002) proposed as public standards of analysis.

Source: The authors.

ANALYSIS OF SCIENTIFIC KNOWLEDGE DOMAINS USED BY THE PROFESSOR

Due to the nature of the classes, the professor revisits content already studied and presents new ones, recurrently mobilizing the conceptual domain of scientific knowledge. Thus, the professor realizes interactions that reveal a traditional teaching approach (Stroupe, 2014; 2015), but other domains of scientific knowledge emerge. Therefore, in this analysis, we describe only the episodes that indicated speech turns that would also allow us to highlight features of other domains, as indicated in the tables below.

In the episode analyzed and indicated in Table 2, the professor resumes discussion with the students, comparing the temperature of some groups of compounds. Purposely, the professor makes a comparison that does not apply, because the boiling temperature of ethers and hydrocarbons with similar molecular weights is very close, and not much higher. The main objective was to verify if the students would perceive the inconsistency in this comparison. The students did not understand, so the professor wrote general structures, "*ROH, R-OR, and R-H*," to represent the functional groups of alcohols, ethers, and hydrocarbons, respectively. From the general structures written by the professor, one student, João, understands the inconsistency of this comparison and responds. Finally, the professor highlights the importance of using the term intermolecular.

Table 2. Transcription of speech turns into an episode about the physical properties of alcohol

T.	Speaker	Transcription of speech	Domains
10	Professor	[…] So just going to show briefly what we saw in the last class… *We started studying alcohol* ((The professor indicates the schemes involving chemical reactions written on the board))… And then we saw their properties… you see that alcohol has a much higher boiling point than ether… which is much larger than hydrocarbon… Is that right?	Conceptual
11	Students	((Some students nod their heads in agreement, but don't say anything))	n.a.
12	Professor	No… Once again? The alcohol has a higher boiling point than ether, which is much higher than hydrocarbon?	Conceptual
13	Marina	No…	n.a.
14	Professor	No… What's wrong?	Conceptual
15	Marina	No… The hydrocarbon is smaller…	n.a.
16	Professor	((The professor is silent for a while, looking at the students)) Once again… Let's go back…	n.a.
17	Students	(Inaudível)	n.a.
18	Professor	*If I ask you to classify alcohol ((The professor solicited students to classify the alcohol, ether, and hydrocarbon in descending order of boiling point))… an ether and a hydrocarbon… How is it classified?* ((The professor goes to the board and start writing the general structure of alcohols, ethers, and hydrocarbons))	Material
19	João	The alcohol has a higher boiling point and ether has a similar boiling point with the/… the hydrocarbon…	n.a.
20	Professor	… hydrocarbon… *Provided that they have*? ((The professor makes a gesture that indicates approximate))	Conceptual
21	João	(___) same mass ((He is referring to molecular mass))…	n.a.
22	Professor	*The same molecular mass… These two are very similar… If they have the same molecular mass…* ((The professor indicates the general structures of ethers and hydrocarbons)) *Now… but the alcohol… Leave forward…… Why?* ((The professor makes a lifting hand gesture to refer to highest boiling point alcohol than ether and hydrocarbon))	Material

Source: Elaborated by authors. T. = turn; n.a. = not applicable.

In turns of speech 10 to 16, the professor, when seeking students' prior knowledge showed a comparison between boiling temperatures between groups of organic compounds, revises a studied content, using the *conceptual domain*. Since the students did not demonstrate that they identified inconsistency in this comparison, the professor writes representations on the board (turn 22) to highlight the differences in boiling temperature, supporting her explanation (*material domain*). In this case, these representations adopt on materiality when they were questioned by the professor, because she exhibits the arrangement of atoms that constitute the functional groups, highlights the predominant type of intermolecular interaction, and explains the difference in boiling temperatures, sustaining her intellectual work and favoring the students' understanding. We understand that the professor relates the content to these representations, which provide conceptual elements (the hydrogen atom directly bonded to the oxygen atom in alcohol would imply a higher boiling temperature than ethers and hydrocarbons of the same molecular mass, and the presence only of the oxygen atom in the ether would imply a boiling temperature similar to that of hydrocarbons), so that students can identify the inconsistency in the established comparison.

In another episode, the professor reinforces the centrality of these representations in Organic Chemistry (Goodwin, 2008; 2010), according to Table 3.

Table 3. Transcription of speech turns on the episode about the reactions that alcohols can undergo

T.	Speaker	Transcription of speech	Domains
103	Professor	So… usually… we write base… because we know that it is a weak base… Let's go… What is the objective of Organic ((Chemistry))? To see how this happens in the microscopic world… For us to see this, we built the mechanism… Let's try to propose this mechanism here…	Epistemic Social

Source: Elaborated by authors. T. = turn; n.a. = not applicable.

In turn 103, the professor explains the reason for the emphasis on building the reaction mechanisms indicated; for her, they allow access to the models that are built to understand and interact with the themes and processes of Organic Chemistry (Goodwin, 2008; 2010). Thus, we understand that the professor explains how the understanding of organic reactions is organized and why it is organized this way (*epistemic domain*). Moreover, the professor once again establishes a norm linked to the use of representations, the need to build the mechanism (*social domain*). Considering that Organic Chemistry books and articles are full of reaction mechanisms, this norm established by the professor is also a routine in this community. Therefore, the use of the mechanism becomes a criterion defined by the professor for evaluating the ideas, indicating the establishment of public standards of analysis, as proposed by Longino (2002).

At another moment in class, the professor was discussing with the students a reaction that makes the hydroxyl group of alcohol a good leaving group, that is, a group that can be easily modified. In this discussion, she presents the possibilities for obtaining the products, based on which compounds are written on the projected slide (in this case, specifically the chloride ion) and which ones should be used to build the mechanism. When the professor was questioned about how the chloride ion would be when carrying out the reaction in the laboratory, she responds to the student by showing the representation of the formed compound. Once again, she uses the representation to support the occurrence of the chloride ion in the reaction medium, as indicated in Table 4.

Table 4. Transcription of speech turns on the episode about the reactions that alcohols can undergo

T.	Speaker	Transcription of speech	Domains
166	Professor	But why/… doesn't chlorine take hold? Because if it takes((…)) it will produce HCl… Is HCl not a strong acid? The strong acid immediately reacts with any base in the medium… Ok? *Here he just puts it in parentheses to show that at the end HCl comes out… HCl has to come out because it doesn't tells us what the base is* ((The professor indicates on projected slide))… But when you are going to make the mechanism, you will always try to capture the proton with the base you have in the medium… Ok? Between chloride and pyridine, pyridine is better… Why?	Conceptual Material
167	Pedro	So ((…)) Is there chloride dissolved in the solution?	n.a.
168	Professor	*Yes… There will be Cl- here* ((She indicates towards the pyridine which will be protonated to form the pyridinium ion))…When it attacks here, what is obtained? Pyridinium… is it not? *When pyridine attacks there* ((referring to formation bond with hydrogen atom))*, you will obtain this here* ((She draws the structure of the pyridinium ion))… Nitrogen with a positive charge… then the chloride will be close to it… obtaining an ionic compound… salt… Ok?	Conceptual Material
169	Pedro	Ah…	n.a.
170	Professor	*At the time that pyridine takes* ((referring to formation bond with hydrogen atom)) *to obtain the pyridinium ion* ((She has shown the formation again))	Conceptual Material
171	Pedro	Does it precipitate easily? This salt?	n.a.
172	Professor	Precipitate… […] When we are in the research laboratory… you need to replace alcohol with some group… obtain for example an amine… If you try to make the amine directly from alcohol ((…)) it will not happen… So, what do I do? I convert alcohol into a good/… in a mesylate to have a good leaving group and then I do the NU ((referring to the attack of the nucleophile))… Another reason we use tosylation and mesylation is to protect the OH group… Ok? How to protect the OH group? […] For example,… you can have a molecule that has a hydroxyl and an alkene… if I try to react with an acid… it will react with both the hydroxyl and the alkene… but I don't want to react with the hydroxyl… I want to react only with the alkene… So, I do a protection of this group… I react with my double and then I come back again with my hydroxyl… […]	Conceptual Material

Source: Elaborated by authors. T. = turn; n.a. = not applicable.

When discussing the occurrence of the acid and base reaction, the professor (turn 166) resumes a content, mobilizing the *conceptual domain*. In the same turn, she uses the experimental material and the representations, mobilizing the *material domain*, when she signals students to evaluate what is in the reaction medium and what can be used to build the reaction mechanism. Thus, when relating to what happens in the laboratory, the professor problematizes the use of these chemical structures in relation to the reagents they represent and what happens after the chemical reaction. In turns 168 and 170, to answer a question from one of the students, Pedro, in addition to the *conceptual domain*, she uses representations and experimental material to indicate the precipitation, also mobilizing the *material domain*. In turn 172, the professor mobilizes the *conceptual* and *material domains* to expose experimental procedures developed in the Organic Chemistry laboratories, respectively, by mentioning the use of a reagent that converts a functional group into a good leaving group, that is, the use of reagents that favor the occurrence of new reactions; and by mentioning the use of protecting groups, that is, the protection of groups of a compound, which cannot be irreversibly altered, for the modification of others of interest. She does this move to establish a relationship with the content that was resumed.

In the episode indicated in Table 5, the professor discusses the reactivity of methyl, primary, secondary, and tertiary alcohols, affirming that methyl and primary cannot obtain carbocations (electron-deficient carbon atom, that is, with a partial positive charge). In this sense, the student cannot represent the structure of a carbocation in the reaction mechanism when involving methyl and primary alcohols. If the reaction occurs with these alcohols, the reaction mechanism must be of the SN2 type (bimolecular nucleophilic substitution reaction). When the reaction involves tertiary alcohols, the formation of the carbocation occurs, and the mechanism is of the SN1 type (unimolecular nucleophilic substitution reaction). In the case of secondary alcohols, if experimentally detected the carbocation is SN1, if not, it is SN2.

Table 5. Transcription of speech turns on the episode about the reactions that alcohols can undergo

T.	Speaker	Transcription of speech	Domains
317	Professor	[…] And when this is a primary and methyl alcohol, we cannot have primary and secondary carbocation formation… This mechanism will not occur when we have primary and methyl alcohol… Before obtaining the carbocation… before obtaining this primary carbocation… the halide already attacks and throws away… Ok… but the reaction is very slow… It has no practical effect when you are using a halide… a primary alcohol… but you are in the laboratory…get an alcohol absentmindedly… a primary alcohol… put it to react and five minutes later you get there and wow?… Did it react to anything? And it will propose the mechanism and make the primary carbocation. I kill huh?… […] Can I propose the same mechanism that I proposed here? No… So, this is a fundamental step… when you add a primary alcohol the reaction […]… starts quickly… When you add a tertiary alcohol… did not react… When you add a secondary alcohol such as this one, there was no rearrangement in the experimental data… So, I have to propose a mechanism… that will be consistent with the experimental data… I cannot under any circumstances… propose a mechanism leading to carbocation obtaining… […].	Conceptual Material Social

Source: Elaborated by authors. T. = turn; n.a. = not applicable.

The *conceptual domain* was mobilized when the professor explained the content about the reactivity of different types of alcohols. Subsequently she uses the experimental material when carrying out the reaction in the laboratory, mobilizing the *material domain*. The professor associates the exposed content to be carried out of the reaction in the laboratory to establish a norm of Organic Chemistry, mobilizing the *social domain*, that one cannot use representations that do not correspond to what is observed in the experimental data. In our interpretation, it is a norm because this relationship between the representations (chemical structures) and the experimental material (experimental data obtained) supports the proposition of reaction mechanisms in Organic Chemistry, indicating a criterion to be considered by the students – which in turn refers once again to the establishment of public standards of analysis, according to Longino (2002). This norm informed by the professor becomes a routine to be considered in her classes and in any study of Organic Chemistry, the coherence in the proposition of mechanisms, as we will discuss in more detail below.

In the turns of speech indicated in Table 6, we observed how important visual representations are for the discussions that occur during classes. In this episode, the professor asks the student Ana to go to the board and make the reaction mechanism that was being discussed. However, the visual representation that would be used by Ana was not accepted by the professor.

Table 6. Transcription of speech turns into the episode about the reactions that alcohols can undergo

T.	Speaker	Transcription of speech	Domains
193	Professor	*Let's go! Draw for me the structure of group X* ((The professor hands the marker to Ana))… What will occur? I have an alcohol and mesyl chloride ((The professor makes a mistake, because it is tosyl chloride))	Conceptual
194	Ana	*I will draw without the stereocenter* ((Ana refers to carbon atom and starts drawing the structure))	n.a.
195	Professor	You can't… It has to be with the stereocenter…	Social
196	Ana	Wow… professor… It can't?	n.a.
197	Professor	*Put the wedge-shaped line here oh* ((The professor indicates in the board. The wedge-shaped line is filled and means that the bond is forward from the plane of the board))… It is true… O ((Referring to oxygen atom))	Social

Source: Elaborated by authors. T. = turn; n.a. = not applicable.

The professor exposes the content related to a type of reaction that alcohols can undergo when presenting the reagents to be used by Ana, mobilizing the *conceptual domain*. However, Ana informs the type of representation she would use, but the professor disagrees. Thus, the professor establishes a norm about the type of representation to be used in this situation, mobilizing the social domain. We understand it as a norm, because, conceptually, the representation to be used by Ana was not incorrect, but, according to the professor, at this moment it would be appropriate to use another type of representation, showing the three-dimensional projection of the compound. In this sense, once again the professor establishes a criterion to be considered by the students, indicating the establishment of a public standard of analysis (Longino, 2002).

As indicated in the episode of Table 7, the professor pays attention to the fact that in a reaction mechanism, one must evaluate the possibilities of formation of the species that compose it. In this case, the use of the curved arrow indicating the exit of the hydride ion would show the presence of a strong base in an acid medium. Although the use of the curved arrow is respecting the rule that one should lose where there are excess electrons, the formation of the hydride would be inconsistent. The professor understands that even if the students attend to the construction rules of the mechanism, there is a need for attention to what is being proposed.

Table 7. Transcription of speech turns involving the episode about reactions to obtain ethers

T.	Speaker	Transcription of speech	Domains
592	Professor	Here the pair of electrons was going to the oxygen atom… here the pair of electrons was going to the hydrogen atom… *This arrow means that H minus is coming out* ((The professor draws the visual representation))… This base is?	Conceptual
593	Students	Strong…	n.a.
594	Professor	Very strong… *So, this here can never occur… good* ((The professor draws on the board))… So… only pay attention to that detail… Because this is a chemical error… I am in an acidic medium and you put a hydride leaving… This leaving group… which is a strong base… There you have no way to take advantage of anything from your mechanism…	Social

Source: Elaborated by authors. T. = turn; n.a. = not applicable.

The professor when comparing the possibilities of movement of the curved arrow in the proposed mechanism exposes the content, interacting with the *conceptual domain*. However, for the professor, even if this movement is conceptually correct, the students need to evaluate what is being formed, so that they do not commit what the professor calls a "chemical error" (turn 594). Once again, these ideas indicate a norm linked to the use of representations used by the teacher for the construction of reaction mechanisms (*social domain*).

The professor understands that the mechanism cannot be built only by conceptual elements, e.g., the correct use of curved arrows, but by the proposition of species that are in accordance with the experimental data and use of representations, which do not lead to the obtaining of species inconsistent with the reaction medium.

In general, we observed that the mobilization of the conceptual and material domains is recurrent, and that the epistemic domain appears in a few moments from the analyzed episodes. The social domain, however, appears frequently, especially linked to the use of representations, according to previous study (Silva & Sasseron, 2021). Although the conceptual domain prevails, the professor makes an interesting move by bringing situations from the laboratory, involving the experimental material on the relation to the use of representations.

DISCUSSION OF RESULTS

We observe that the mobilization of the conceptual domain is recurrent and that the same does not occur with the epistemic domain which rarely occurs, revealing marks of a traditional teaching approach from the information collected for analysis (Stroupe 2014; 2015). This can be related to the characteristics of the classes, in which the professor revisits the students' prior knowledge to present new ones, establishing norms often linked to the use of representations (Goodwin, 2008; 2010; Hoffmann and Laszlo, 1991; Laszlo, 1998;). In addition, the recurrent use of representations in this professor's classes may occur due to the very nature of Organic Chemistry (Goodwin, 2008; 2010).

Based on the ideas of Longino (1990; 2002), we observe that the norms and routines of Organic Chemistry established by the professor are close to what the author proposes as a social norm of knowledge, the establishment of *public standards* of analysis. This is because the professor uses criteria defined in and by the Organic Chemistry community (Goodwin, 2008; 2010) to establish how students should proceed to build understandings regarding the discipline's themes and processes, e.g., the assessment of the pertinence of the proposed species for the building of reaction mechanisms. The professor establishes norms and routines, and evaluation criteria (Longino, 2002) that are her own, such as the use of determined terms and types of representations. Thus, the social domain is often already established by the professor. However, Duschl (2008) and Stroupe (2014) propose that it should not only be established, but that its negotiation with students should also be provided. We understand that the low occurrence of the epistemic domain in the analyzed episodes may have contributed to the fact that the social domain was only established, and not negotiated, showing features of a traditional teaching approach, as we have mentioned previously (Stroupe, 2014; 2015).

The professor interacts with the epistemic domain and, frequently, with the material domain when relating the experimental material and the use of representations, even having features of a traditional teaching approach. She interacts with the epistemic domain, because she emphasizes the coherence between the experimental data and the representations used to build the proposed mechanisms, which allows for the construction of understanding about the themes and processes of Organic Chemistry. Thus, she seeks to establish a relationship of meaning between experimental measures/data and representations, giving them legitimacy by explaining the reason for this relationship and why she is convinced of what was presented (Duschl, 2008; Stroupe, 2014). The professor interacts with the material domain because, for her, concrete and abstract materials are not just accessories in the processes of building understandings in the classroom, but provide a central role (Pickering, 1995; Stroupe, 2014). The professor establishes a direct relationship with what happens in the laboratories, questioning the use of reagents, solvents, glassware, and representations that constitute the organic chemistry laboratory according to several moments of the episodes presented in this paper. On the turn 60, e.g., when the professor emphasizes "*Then the other flask... can't be together*," she is implicitly showing that the reagents available for the reaction must be in different vials and there is an order in which they are added. If this situation were taking place in the laboratory, we could say that not only does the teacher act on the materials but, at the time the activity occurs, if the materials were not available there, it would be impossible to carry out the chemical reaction. In other words, the construction of understandings in the classroom also occurs from and with the materials available at the time the activities concretize (Stroupe, 2014).

The relationships that the professor establishes between the experimental material and the representations occur to link them to their production context. This professor's approach is close to the proposal by Evagorou *et al*. (2015) that based in Pauwels (2006), defend the inadequacy of approaching visual representations[2] as a product for science teaching, because it would provide an image of representations as independent of scientific work, which they are not. For the researchers, a process approach would be necessary in which each visual representation would be linked to its production context. Thus, Evagorou *et al.* (2015) position visual representations as epistemic objects, justifying this position by the fact that visual representations are involved in the process of construction and development in science. Therefore, "*what is of importance in this process is not only the result but also the methodology employed by the scientists, namely, how this result was produced*" (Evagorou *et al*., 2015, p. 3). This does not mean that the researchers defend doing in the classroom what scientists do, but an approximation to a more authentic approach to scientific activity (Stroupe, 2015).

In this perspective, we agree with Evagorou *et al*. (2015) when positioning visual representations as epistemic objects, but we understand that it is not enough to just link them to the production context. As previously mentioned, and thinking about the students' learning, the professor links the use of representations to their production context, but the visual representations, as well as the modifications that occurred to generate new representations, are already provided and the conceptual developments are also informed. Therefore, visual representations are not problematized, that is, everything that is known about them has already been presented.

Discussing the results of our analyzes and seeking to complement the ideas of Evagorou *et al*. (2015), we looked toward the studies by Rheinberger (1997; 1998; 2005) to justify our understanding of epistemic objects in relation to the teaching and learning process. The ideas presented by Evagorou *et al*. (2015) and Rheinberger (1997; 1998) about visual representations converge to the same understanding that, while they are a product of scientific activity, they are necessary for the production and development of knowledge. Rheinberger (1998), defending representations as components of epistemic objects, affirm that they are allowed by experimental systems, which are the experimental devices that produce answers, but at the same time shape the questions to be answered, co-generating material entities, phenomena, practices, and concepts (Rheinberger, 1997; 1998). When the professor says "*So I have to propose a mechanism... that will be consistent with the experimental data... I cannot under any circumstances... propose a mechanism leading to carbocation obtaining... [...]*" (Table 5), she approaches the concept of experimental systems because it involves concepts, apparatus (which also allows generating experimental data), representations, norms, routines, and practices (Rheinberger, 1997; 1998). In our interpretation, it is similar because the answers are not produced together with the students, but are already presented, that is, everything has already been communicated to the students. For Rheinberger (2005), objects are epistemic when we need to know more about them. To develop this discussion, we will seek the idea of mutability of the roles of objects proposed by Rheinberger (1997).

The mutability of object roles refers to the transformation of technical objects into epistemic objects and vice versa (Rheinberger, 1997). There are two main forms for the transformation of epistemic objects into technical ones: when they become untenable as targets of preoccupation under scrutiny and when they cease to provide a function, during the investigation process (Rheinberger, 2016). Thus, epistemic objects are characterized by not knowing about them and by their indeterminacy as to their obsolescence as research targets. Technical objects are determined and defined by the boundary conditions of other epistemic objects (Rheinberger, 2005). In our analysis, just linking visual representations to production contexts does not position them as epistemic objects because there is a need for them to provide a function and/or be an object of interest to know more about it.

Therefore, to provide the construction of understandings for the students, the professor treats the representations as technical objects. In the sense, she approaches the representations linking them to their context of production, sustaining her intellectual work, but not for the students. In her classes, the representations, including those linked to the context of production, are already determined with well-established functions when she exposes them to the students. We are not defending that representations should be treated as epistemic objects in all moments. According to Rheinberger (1998), in an experimental system, while the epistemic object becomes technical, there are openings for the emergence of new events. However, considering the students' learning, treating the representations not only as technical objects, but also as epistemic objects can be advantageous since the representations will be perceived as necessary for the construction of understandings in the classroom, as well as generating possibilities for new understandings.

CONSIDERATIONS AND IMPLICATIONS

When we analyze the interaction of a professor with the domains of scientific knowledge in an Organic Chemistry classes for Higher Education Chemistry students, at a public university in the state of Minas Gerais, we observe that the conceptual and material domains arise frequently; the epistemic, rarely; and the social domain occur linked to the use of representations.

The professor establishes norms and routines, not open spaces for negotiation. We understand that there are moments in which norms must be established, but we defend that interaction with the social domain cannot occur by presenting a list of norms and routines, but by experiencing them in their creation, which occurs with negotiation. Thus, these norms and routines need to emerge beyond the relationship with the contents, but in the evaluation of what counts as understanding that will be constructed by the students. This movement is carried out by the professor who has already been initiated and is already a practicing member of this community.

The professor uses representations beyond the communication of knowledge, one that is linked to norms and to her production context. However, since the function of the representations in this context of production seems already well determined by the professor, we understand that, in the relationship with the students, she positions these representations as a technical object (Rheinberger, 1997). In other words, the representations, although linked to their production contexts, are not subjected under analysis, either in terms of the function they provide or in the developments generated from them for the construction of understandings in the classroom.

Based on the considerations we have here in exposed, we can present some implications for the teaching of Chemistry and research in Science Education.

For the teaching of Chemistry, we present two implications that have already been presented by the literature, but which we believe can contribute to its understanding: First, to position the representations as epistemic objects, linking them to their production contexts, but, above all, submitting them for investigation. It is not enough to inform and/or show students the production process of these representations, but to involve them in the investigative process, acknowledging that, while they are generated from it, new investigations can come from its use. Second, to reflect on curricula and learning environments in Organic Chemistry in Higher Education. According to several studies on experimentation (e.g., Hodson, 1994; Silva *et al*., 2010; Novais, 2018), we understand that there is no support for the dissociation of Organic Chemistry into theoretical and experimental, which is still established in some institutions.

For research in Science Education, we present theoretical-methodological implications regarding the characterization of the social and material domains in relation to the activities to be developed by students. The characterization of the social domain is not only given by the features of a collective and collaborative work by the students but also involves critical interaction (Longino 1990; 2002). In other words, the social domain is not characterized only by the fact that students participate in group work, in which norms and routines are already informed by professors. This domain is characterized by the interactions allowed by the participation of students in situations that demand the reproduction and/or negotiation of norms and routines while the group experiences them. Regarding the material domain, as mentioned in the introduction, there are only a few studies, making it difficult to understand how it can be characterized. Considering that material domain refers to the ways in which tools, technologies, and inscriptions are produced, adjusted, and applied to support the intellectual work of practice (Stroupe, 2014; 2015), we propose the characterization of this domain, based on the activities to be developed by students, through the positioning of these concrete and abstract materials not only as technical objects, but, above all, as epistemic objects. In our interpretation, in relation to the activities to be developed by the students, these materials cannot support the intellectual work of the practice if they are treated only as technical objects while performing an epistemic function and/or being positioned as a target of interest to learn more about them (Rheinberger, 2016). When all information about these materials is already provided to students and the consequences of their use are already determined previously, the possibility for investigating and negotiating norms can be suppressed.

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Statement on data availability

The entire anonymized data set that supports the results of this study was made available in the SciELO Dataverse.

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1 To demonstrate the categorization, we used a transcription in which the three material, conceptual, and epistemic domains appeared in the same turn of speech. Subsequently, in another turn, the social domain was mobilized. The characterization of the social domain was based on a previous study (Silva & Sasseron, 2021), in which it was identified that the norms established by the professor are often associated with the representations.

2 Evagorou *et al.* (2015) use the term visual representations, in the conception proposed by Pauwels (2006), as a generic term that covers the various types of external representations, referring not only to purely mental, conceptual, or abstract constructions but also referring to some object which may have some kind of material or physical existence.

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