Journal of Turkish Science Education, 2022, *19*(3), 786-807.
DOI no: 10.36681/tused.2022.150

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

The Role of Time in The Use of Visualization in Chemical Education: Pre-Service Teacher Practices

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ABSTRACT
This exploratory study investigated the relationships between time utilisation and the use of visual resources, supported by audiovisual records of the practices of pre-service chemistry teachers applying Teaching-Learning Sequences. The content analysis was based on analytical categories found in the scientific literature. The results showed a positive association between increased time spent using visualizations, diversification of pupils' actions, and the quality of the students' verbal interactions, through the predominance of conceptualisations in the submicro domain, with transitions between the macro and submicro domains. This study reinforces the importance of reflecting on the different ways of using visualizations in classroom time during chemistry teacher education, and the challenges of building and implementing chemistry teaching practices with scientific visualizations that are more integrated into the school curriculum.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received: 12.10.2021
Accepted: 08.05.2022

KEYWORDS:
Chemistry teacher education; time utilisation; visualization.

To cite this article: Silva, A. J. P. & Arroio, A. (2022). The role of time in the use of visualization in chemical education: Pre-service teacher practices. *Journal of Turkish Science Education*, *19*(3), 786-807.

Introduction

Driven by economic demands and technological transformations, new ways to experience time have accelerated the pace of social life, with important political and cultural implications (Harvey, 2008). In this accelerated way, images supported by digital technologies become part of the compulsory consumption arrangement of ephemeral, homogeneous, and repetitive content that overlaps with the act of seeing, reducing the ability to associate such content with ethical and social evaluations (Crary, 2016).

Thus, the time needed for the critical reading of images becomes important, since image enhancement has been used to promote the ideas of both news agencies and government policies (Bannatyne et al., 2019). In addition, when passively observed, visual content in videos, photos, and virtual reality can facilitate the reception of fake news in decisive historical moments (Liv & Greenbaum, 2020). The increased use of images in social-media-based communications, especially in interactions between young people, reinforces the relevance of studying the relationship between images and the time spent viewing them.

But the influence of this accelerated time from consumer society that stimulates non-critical reading of broad range of images that it makes available also must be investigated in the classroom time. Especially since the classroom should be a confluence between the everyday life and scientific world, in which notions of time and ways of perceiving images can intersect. The ability to relate science concepts (scientific world) to surrounding social world (everyday life) is an important indicator of citizens' scientific literacy as well as nowadays visual literacy is one of its key aspects.

In this regard, the study carried out by Cepni et al (2017) on pre-service teachers' views of the process of associating scientific concepts with everyday life showed that prospective teachers were aware that this process was very important. This association process was perceived more intensely as the transfer of scientific knowledge to everyday life, while less emphasis was placed on recognising or understanding scientific knowledge in everyday events or situations.

In our view, the process of association between Chemistry and everyday life can also reveal teacher's role in selecting, making available and exploring a vast array of images supported by digital or analog devices and stemming from different contexts, scientific and non-scientific. Then, knowing the different contexts and supports of images in function of the time allocated for their use becomes equally important.

Studies have shown the relevance of the teacher for successful use of digital technologies in school, for ensuring adequate time for learning scientific concepts, and for helping pupils learn with scientific images. For instance, in the high school context marked by the highly intense use of digital technology for learning, such as smartphones, Putranta et al (2021) found that this tool use had a relatively small effect on the Higher Order Thinking Skills of learners (HOTS) who participated in the study. The research pointed out the very important role of the teacher in stimulating, supervising and guiding the use of these tools for educational needs in order to create an effective environment for the prudent use of digital devices by the pupils and within effective didactic strategies that lead to the optimisation of the HOTS.

In turn, the abilities to create a conducive learning environment and to select and use appropriate instructional strategies that meet the pupils' learning needs emerged as the main characteristics of an effective teacher in pre-service teachers' conceptual understanding in the study performed by Adu Gyamfi (2020). The time factor was prominent. Time consciousness appeared as teachers' awareness of using class time for the benefit of learners. The importance of efficiently providing institutional time for student learning has permeated ideas such as an effective teacher "takes time in teaching scientific concepts and ideas" and "an effective teacher avoids rushing students through scientific concepts" (Adu Gyamfi, 2020, p. 51).

In Chemistry Education this awareness of time to avoid a rushed teaching through concepts also presupposes an allocation of time for the understanding of its visual representations (with their codes, rules, conventions and representational meanings). This is because the reading of scientific images (visualisations) at school is not simple or trivial, and the teacher's role is crucial when sensitised to these reading difficulties (Pintó & Ametller, 2002), i.e., when they become aware of how pupils process the images' messages (Colin et al., 2002). Teachers are responsible for allocating adequate time and effort to explore potential and false meanings with their pupils (Stylianidou, 2002).

According to Larrosa (2018), this adequate time should be a "counter-time", that is, a slow time (not accelerated), not fragmented, not homogeneous, and not guided by digital devices. This time is not determined by the duration of exhibition or handling the digital resource, but by the time of reading and writing. School processes should maintain a certain desynchronisation with the dominant social times and temporalities, in which acceleration destroys attention, in order to be open to the emergence of true experiences that are needed for the formation of attention and consciousness.

These theoretical bases, accordingly, suggest that while ways of reading images in everyday life tends to be accelerated and detrimental to deep understandings, classroom time needs to be appropriately slowed down for learning abstract scientific concepts with complex visual representations (visualizations). However, research has not systematically and thoroughly addressed the relationships between time utilisation and visualizations, from the secondary school teacher's perspective.

Santos & Arroio (2016) found a gap in the scientific research related to chemistry teacher education in using visualizations. In general, the conceptual repertoire of teachers on the subject has been incomplete and insufficient. Initial naive perceptions, possibly resulting from intuitive use, have been observed (Ferreira et al., 2011), and the small amount of knowledge acquired seems to be based on the teachers' previous experiences, both as students and in their own pedagogical practices (Eilam, 2012). Pre-service teachers have built their knowledge spontaneously, mainly from everyday experiences with visualizations through the media, and exposure to these resources in higher education (Eilam et al., 2014).

The time factor appears as an epiphenomenon of the few studies on the use of visualizations in secondary education. In these studies, time (or lack of it) is pointed out as one of the main obstacles to the effective use of various visual representations, such as static images, animations, and scientific simulations (in the next section), but it is not studied systematically. In view of that, this research seeks to contribute to the expansion of studies on the relationships between time utilisation and visualization in the context of teacher education.

Time and The Visualization Process

Eilam (2012) investigated the use of visualizations in the classroom and found that teachers often intuitively feel that their use could shorten instructional time. In this naive perception, the simple act of the pupils looking at a visual representation would reduce the class time allotted for them to talk a lot about the represented subject. The use of visualizations was also perceived as "wasting lesson time" (p. 78) since the visual resources could draw the pupils' attention to erroneous aspects and the teachers would not be able to check all the misunderstandings generated.

The lack of time to explain these misunderstandings or to dedicate a fraction of the class to the study of visualizations has also been seen as one of the obstacles to their use. This has been occasioned by the time pressure exerted by the large amount of teaching content and learning objectives (Eilam, 2012; Eilam & Gilbert, 2014b).

Some studies have related chemical representational domains to verbal interactions between teacher and students. Li & Arshad (2014a, 2014b, 2015) investigated the practice of wait-times involving visualizations, i.e., the pauses allocated after the teacher's question and after a student's answer. They find that these wait-times are critical for students to understand the question and think about the content and elaboration of their answers.

Other studies have analysed teaching strategies based on the learners' own constructions of visual representations of scientific concepts. Strategies characterised by a strong and explicit emphasis on constructing, negotiating, and refining of representations (Tytler, Hubber, & Prain, 2013; Tytler, Hubber, Prain, & Waldrip, 2013). Waldrip & Prain (2013) reported that teachers noted the need for more time at the beginning of the implementation of these practices compared to their previous practices. The benefits of allocating time for students to learn representational conventions were also perceived.

In this context, Hubber (2013) showed that teachers saw the importance of allocating more time for the negotiation and discussion of representations during the lesson-planning stage. Giving pupils enough time to formulate and consolidate their ideas was seen as one of the positive impacts of this strategy.

In the same vein, Parnafes & Trachtenberg-Maslaton (2014) showed the relevance of allocating time for pupils to create their own visualisations. The authors showed that visual representations externalised by the pupils served as an anchor for classroom discourse, sparking authentic dialogue, and promoted an easy and immediate exchange of ideas, feedback, argumentation, and pertinent corrections.

Loughran (2014) outlined the "slowmation" teaching strategy, i.e., the creation of dynamic visualisations by the pupils themselves involving scientific concepts and using low cost and low technology (a series of photographs is recorded with a digital camera and then it is edited into the form of a video). Eilam & Gilbert (2014a) mentioned that this strategy decelerates informational flow and thus "enables the user to understand the individual concepts more clearly being represented". It turns "abstract ideas into a concrete form, thus making them more mentally accessible" (p. 52).

According to Loughran et al. (2012), this deceleration in the use of dynamic visualisations makes teachers more sensitive to pupils' alternative conceptions. These conceptions can be perceived during the creation of their storyboards or the presentation of their slowmations in class. By using this strategy, future teachers realised that "simply telling students what they 'should know' does not have the desired effect on students' understanding of a concept", (Loughran et al. 2012, pp. 99–100) - they recognised the limitations of teaching approaches that are merely transmissive.

Animations produced by experts also have great teaching potential, especially for scientific concepts involved in phenomena or processes that unfold over time. In this context, a teaching strategy consisting of a sequence of seven key moments is described by Tasker & Dalton (2006). The pedagogical work with animations starts with a simple display of the visual resource and its interpretation, and progresses to its insertion into a set of systematic writing, drawing, and oral discussion activities that promote the creation and externalisation of visual mental models. Evidence of the effectiveness of this deceleration in the use of animations was highlighted by Tasker et al. (2003): "The most significant change since inception in 1994 was taking the time to elicit the student's prior views before showing the VisChem animation" (p. 02).

Geelan & Fan (2014) proposed a flexible, dynamic, and open-ended inquiry-based approach for the use of interactive simulations. In general, their sequence of actions involves discussions in small groups and with the whole class, eliciting the students' preconceptions and understanding of scientific concepts targeted by simulation, predictions of phenomenon behaviours, and written records. The teacher has a central role in supporting the discussions and argumentations that are triggered throughout all stages.

The authors exhorted the importance of this expanded time with simulations because "just as students learned to read and write text, they need time and support to learn to 'read' visual representations" (p. 258). For Geelan & Fan (2014), in curricula overloaded with content "there is often insufficient time to more fully develop concepts". However, it is necessary to ensure more time for teaching complex concepts (e.g., using simulations) because "a speedy exposure only tour of concepts does not lead to real, internalized learning" (p. 265).

A temporal demarcation is evident in teaching proposals in which verbal interactions, the practice of creating visual representations by students, and the use of visual resources supported by digital devices, are distributed among perception and interpretation tasks. It can also be perceived in refining visual information that supports the acquisition of representational competence, and in the creation of mental models that are suitable for the development of abstract and complex conceptual thinking. Pedagogical assumptions bring implications for the critical use of time with visual resources in the context of teaching and learning chemistry.

Objective of the Study

The objective of this study was to investigate the relationship between time utilisation and the ways of using visual resources that emerged during the implementation of teaching-learning sequences (TLS) by pre-service chemistry teachers. The study sought to answer the following question: In a context in which scientific and non-scientific visual resources must be mobilized in teaching practice, how do pre-service teachers use time with visual resources – whether phenomena, objects, or representations – to specifically promote the visualization process in Chemistry?

Method

This study used the qualitative research method. This, according to Patton (2014), preserves a study's naturalistic dimension, in that the researcher does not try to affect, control, or manipulate the study object, allowing it to unfold naturally. At the same time, intentional sampling was used, focusing on relatively small and purposively selected samples to enable a deep and information-rich understanding of specific cases. The method was supported by the interpretive paradigm which, according to Tracy (2013), assumes that the knowledge about reality is socially constructed through communication, interaction, and practice, and it is the researcher's role to make an effort to understand it. The study was supported by content analysis (Bardin, 2011), based on thematic categories found in the scientific literature (Visual resource, Semantic content, and Pupils' actions).

The Context and Framework of Study

To respond the research question, a broader study was carried out which involved the analysis of TLS planned and implemented by pre-service teachers. This is called teaching practice in this article. This analysis from the perspective of the ways of using time with chemical visual resources needed a context to stimulate the use of different types of visual resources (chemical and non-chemical). This stimulus was achieved by planning thematic teaching-learning sequences (TLS). This article reports the results of the analysis of two of the four thematic TLS produced by them (these are called TLS2 and TLS3 in this article). A description of one of the thematic TLS implemented is shown in Appendix A. The use of non-chemical (thematic) visual resources was considered as a potential distractor element, since the possibility of allocating more or less time to those could imply a correspondingly lesser or greater time allocation to chemical visual resources.

Thus, three aspects characterised the context of teaching practices: a) the planning of thematic TLS was done by pre-service teachers' group and based on major themes (ethnoknowledge, war, media, and art) pre-established by the teacher (second author of this article); b) enough time for planning was provided for the pre-service teachers (two academic semesters, in Methodology of Teaching Chemistry I and II courses, with 60 class-hours each); c) adequate space-time for thematic TLS implementation was made available.

Regarding the latter aspect, in the infrastructural dimension, a classroom with a bench for experiments, Internet access, multimedia projector, blackboard, and appropriate desks and chairs was made available. In the time dimension, the workshops (thematic TLS implementation) were implemented on two different days of the week and up to two hours long each meeting.

From these general themes (ethnoknowledge, war, media, and art), the groups developed sub-themes of their own choosing, selected the relevant chemical knowledge, and began constructing thematic TLS in the first semester. This type of planning discouraged the use of ready-made teaching sequences available in the literature or in repositories during the planning practice, as well as minimising the insertion, in a mechanical, direct, and uncritical way, of tasks and activities from these sources into the teaching plans.

At the beginning of Methodology of Teaching Chemistry I course, a theoretical reference was agreed upon to provide pedagogical structure and coherence to each TLS. The notion of narrative, with its introduction, development and conclusion was assigned to the planning process, as well as the different teaching purposes proposed by Mortimer and Scott (2003). According to the authors, the teaching purposes which structure a teaching-learning sequences are: opening up the problem; exploring and working on students' views; introducing and developing the scientific story; guiding students to work with scientific ideas and supporting internalization; guiding students to apply, and expand on the use of, the scientific view, and handing over responsibility for its use; and maintaining the development of the scientific story (Mortimer and Scott, 2003, pp. 25-26).

This theoretical reference provided a structural basis (initial problem/challenge, presentation and development of chemical and thematic meanings, and final evaluation) for each TLS and its use was compulsory. To overcome potential interferences, the planning practices were started in the first semester at the end of which a first version of the thematic teaching-learning sequences (TLS) was implemented for pupils of Secondary Education. After the first implementation, a critical reflection on the first interventions was requested in order for the thematic TLS to be redesigned and improved.

At the beginning of the second semester and after the implementation of the first version, two sources were made available that illustrated modelling practices with visual resources (visualisation strategies) (Pinto et al., 2014; Vries and Arroio, 2017). The latter were used to stimulate reflections and were not compulsory to be used in the planning. In the second half of 2019, the thematic TLS continued to be refined until the second and final implementation, which was the data source for the analysis (see Appendix B).

Participants

The study was conducted in 2019 in Brazil, São Paulo state, with a group of 14 pre-service chemistry teachers taking Methodology of Chemistry Teaching I and II courses, who built and implemented four thematic teaching-learning sequences (TLS) aimed at pupils aged 15–17 years of age. In this paper the results of two thematic TLS are reported, with TLS2 was implemented by three and TLS 3 by four pre-service teachers.

Data Collection Instrument

The data were collected through audiovisual records of the thematic teaching-learning sequences. The main characteristics of thematic TLS are shown in Table 1. According to Luckmann (2012), these records preserve the essential aspects of the interactions and their temporal and sequential structure, allowing the analyst to "re-experience" the original interaction and make an effort to reconstruct it.

Table 1

General Features of Thematic Teaching-Learning Sequences

Teaching-Learning Sequences	General features				
	Duration *(hh:mm:ss)*		Chemical knowledge	Sub-theme *(Connection point)*	Theme
	1st day	2sd day			
TLS2	01:52:11	02:01:44	Molecular polarity Inter-molecular interactions	The extraction of plant pigments by indigenous peoples and the biopiracy problem	Ethnoknowledge
TLS3	01:24:53	01:52:43	Physical states of matter Diffusion and effusion of gases	The relationship between science and war through the use of chemical weapons such as chlorine, phosgene and mustard gases and sarin throughout history	War

The situational arrangement was close to that of a "natural" situation, as the events during the teaching practices were not dependent on the recording, Knoblauch et al. (2012). Ethical requirements, such as the preservation of anonymity and the request for image rights for research purposes, and the voluntary participation of those involved, were administered by the educational institutions involved.

Data Analysis Procedures

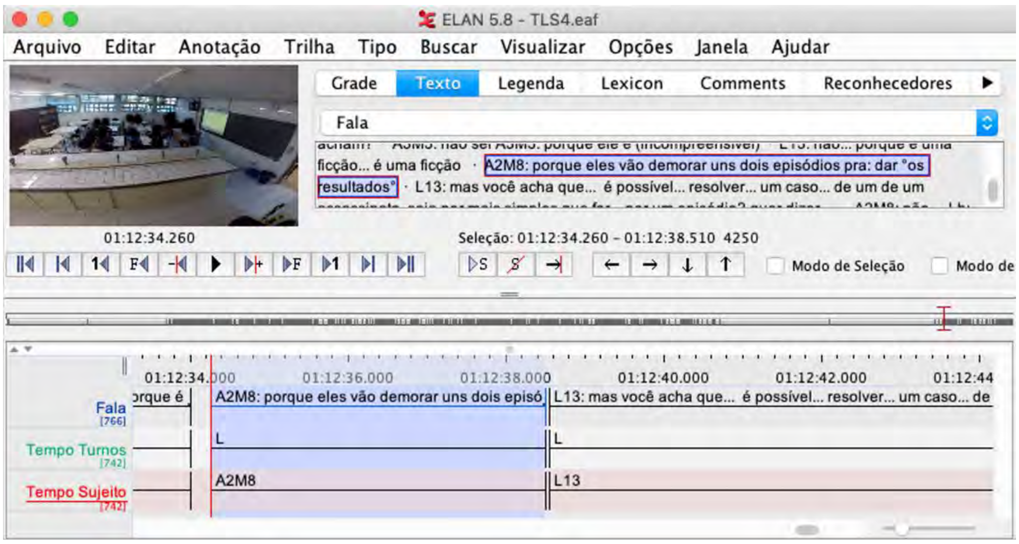
The familiarisation with the data was performed during the transcription of the speech between the pre-service teachers and the pupils in verbal interactions with the whole class using the ELAN software (Version 5.8). Verbal interactions in peer discussions or paper-and-pencil tasks among pupils, in which the focus was not on the systematic intervention of pre-service teachers, were not transcribed.

The transcription work lasted for two months. Two cycles of coding were engaged in to ensure reliability. First a specific code was used as A2M8 (pupil two at desk eight) and L13 (pre-service teacher thirteen). Subsequently, a second coding cycle was performed using general codes, just A (for pupils) and just L (for prospective teachers). When these two encodings were juxtaposed, the total time values of pupils and pre-service teachers turns in each cycle were compared. This comparison work and was used to review the authorship and timing of the turns until the times corresponding to the two cycles were equal.

In Figure 1, an example is shown for TLS4, in which A2M8 (pupil) and L (pre-service teacher) presented a discordance point that was remedied after re-listening to the recordings. Reviewing the audiovisual record at this point, the duration and authorship of the turn was verified and confirmed for A2M8 (and recorded on the first track, from top to bottom). In the next turn, we see that the encodings L (second track) and L13 (third track) confirm the authorship of the turn to L13 (first track). At the end, the transcripts were reviewed by an external researcher.

Figure 1

Example of Checking Transcriptions in TLS4



The written transcripts were imported into the MAXQDA 2020 software (Version 20.4.0) and associated with their respective audiovisual records. In this software, the occurrences of different forms of time use were coded using analysis categories and codes based on the scientific literature (Bardin, 2011). After the pilot analysis, the focus was determined and analysis unfolded into three poles: visual resource (object), pre-service teacher (speech), and pupils (actions).

The first author participated as a monitor while the second was the teacher of the course in which the thematic TLS were implemented. From a broad understanding of the pedagogical context of data collection, both authors separately performed their coding. The results of the process coding were cross-checked, discussed, and refined until a consensus was reached.

Analysis Categories

The teaching resources were considered to be the concrete and physical supports that convey visual or non-visual resources and assist in both the teaching and learning process and the development of the thematic teaching-learning sequences. These codes emerged from the teaching practices. In Appendix C, the category of analysis called *teaching resources* is shown and its codes contain both digital teaching resources such as video, simulation and slide projection, and analog ones such as printed paper, blackboard, reagents and glassware.

The non-verbal visual resources related to chemical knowledge were codified based on Talanquer (2011). From this perspective, the experiential domain is constituted by descriptive, concrete, and empirical knowledge acquired through the senses or mediated by instrumentation. Thus, the non-verbal visual resources coded as experiential were constituted by objects (e.g., glassware, reagents) and phenomena (e.g., solution colour) on the macroscopic scale. Their visual representations were also included in this code (video recordings of didactic experiments, photographs of solid substance samples).

Many chemical representations combine both symbolic and iconic values in their signification and communication processes (Talanquer, 2011). Even assuming this ambiguity, molecular formulas, structural formulas, reaction equations, and graphs were coded as symbolic representations, while iconic representations were formed by ball-and-stick molecular models and particulate representations of matter. The non-verbal visual resources used to explore non-chemical meanings were coded as thematic. In Appendix D, the analysis category named *visual resources* is shown with its four codes (experiential, symbolic, iconic and thematic) and their respective inclusion rules.

Semantic content found in the pre-service teachers' speech shifts during the time available for different visual resources were coded according to Taber (2013). For that author, the phenomena observed in the experiential domain can be re-conceptualised both in the macro domain – involving, for example, concepts such as solution, reversible reaction – and in the submicro domain, where it involves concepts such as atom, molecule, electron, orbital, ion, etc. The set of symbolic representations can also represent and communicate concepts and models elaborated in both macro and submicro domains.

In Table 2, is shown the *semantic content* analysis category and examples with representative excerpts for each of its three codes obtained during the coding stage.

Table 2

Semantic Content Category and its Codes

Codes	Representative extract
Macro domain (M)	A1M6: It is: only that... it is a thing called sublimation and re-sublimation L6: It is then, this r, in fact, it is optional... can be... in a... does not need to include... separate <u>sublimation</u> L13: So, but...eh...what is this...what is this <u>re-sublimation</u> or <u>sublimation</u>? What is it? A1M2: Sublimation is when it goes from solid direct to gaseous...
Submicro domain (S)	A2M2: Because it has carbon L20: Does he have one? A2M2: The same chain L20: A *long chain* A2M2: That's it! L20: So, it can make *interactions... with* alkane *chains*, through that large portion... L20: But it also has... a carboxylic acid so it would be able to make *hydrogen interactions* A2M2: Yes, that! L20: But the *molecule* as a whole has a certain *polarity*...
In both domains (MS)	L20: And then, the <u>solvent</u> with which it had more... affinity, were the (nonpolar) <u>solvents</u>... in the case with *hydrogen interactions*, but they are also not totally *nonpolar*...

Note. Underlined terms: macro; italics terms: submicro.

A category was created to consider the fact that resources and interactions related to the construction of chemical knowledge can be deeply explored in teaching approaches that favour the elaboration and refinement of mental models. Based on Tasker & Dalton (2006), codes were developed to generalise the types of external representations or phenomena involved in seven types of pupils' actions, such as the observation of phenomena or representations, the explicitness of the students' previous ideas, the engagement in the elaboration and re-elaboration of mental models, and the externalisation of the constructed model in new and similar situations. In Table 3, the analysis category named *pupils' actions* is shown with its seven types of actions as well as their respective inclusion rules.

Table 3

Pupils' Actions Category and its Codes

Codes	Inclusion rule
Observe (OP)	The time allotted for the pupils to observe a phenomenon or its representation as a conceptual target of chemistry
Elaborate and externalize (EE)	The time allotted for the pupils to elaborate and externalize a representation that explains an observed phenomenon
Discuss (D)	The time allotted for the pupils to establish relationships between the externalized representation and the observed phenomenon
Observe the canonical visual model/representation (OM)	The time allotted for the pupils to observe the canonical visual model/representation that explains an observed phenomenon
Reflect and review (RR)	The time allotted for the pupils to identify the limitations of an externalized representation in contrast to the presented scientific/curricular visual model, and then elaborate and externalize a new and revised representation
Relate (R)	The time allotted for the pupils to relate an external visualization to another representation in a different domain, both representing the same phenomenon
Adapt (A)	The time allotted for the pupils to adapt and externalize a representation to explain another phenomenon similar to a previously observed phenomenon

Thus, the four categories of analysis (*teaching resources*, *visual resources*, *semantic content*, and *pupils' actions*) were used to investigate the ways of time utilisation in classroom with the various non-verbal visual resources during the thematic teaching-learning sequences. As well, these categories were used to look for the implications of time utilisation in the visualization process in chemistry, that is, of constructing chemical meanings with visual representations.

Results

The Time Utilisation with Thematic and Chemical Visual Resources

Table 4 shows that TLS3 presented 48% (520 sec.) of the time utilisation with the use of thematic visual resources (TVR) and 52% (558 sec.) with the use of chemical visual resources (CVR). The latter evidenced a significant displacement of the use of time in favour of the availability of chemical representations (486 sec.) considering symbolic, iconic, and multiple representations (iconic + symbolic) together, leaving the use of visual resources of the experiential field with only 72 sec.

Table 4

Times Utilisation with Visual Resource in TLS2 and TLS3

Teaching-Learning Sequences	Visual resources				
	Chemical				Thematic
	Exp	*Ico*	*Sym*	*Sym + Ico*	*T*
	Time (s)				
TLS2	384	-	888	-	745
TLS3	72	193	119	174	520

When the visual resources were made available in TLS2, 37% (745 sec.) of the total available time was used with TVR, and 63% (1,272 sec.) with CVR. In this case, there was also a shift in the use of time, although smaller than in TLS3, in favour of the availability of chemical representations (888 sec.), leaving the use of visual resources from the experiential field with 384 sec. Thus, both TLS presented a predominance of CVR over TVR, also with the predominance of chemical representations over visual resources of the experiential field.

Table 5 shows a similar behaviour between TLS3 and TLS2 because their TVR were mostly supported by only one type of teaching resource, Se (489 sec.) and VN (562 sec.), respectively. Another similar aspect was that TLS3 and TLS2 predominantly used four types of media to support chemical visual resources: on the one hand, V, Sm, Se, and P, and on the other hand, Bb, P, Se, and R, respectively.

Table 5

Distribution of Time Utilisation with Teaching Resources According to Visual Resource

Teaching resource	Visual resource									
	TLS2					TLS3				
	Exp	Sym	Ico	Sym+Ico	T	Exp	Sym	Ico	Sym+Ico	T
	Time (s)					Time (s)				
Sp	-	-	-	-	100	-	-	-	-	4
Bb+Sp	-	221	-	-	-	-	-	-	-	-
P	-	-	-	-	-	-	111	-	-	-
P+Sp	-	243	-	-	-	-	-	-	-	-
R+Sp	384	-	-	-	-	-	-	-	-	-
Se	-	-	-	-	-	-	-	-	-	27
Se+Sp	-	410	-	-	83	-	8	-	174	489
Se+Bb+Sp	-	14	-	-	-	-	-	-	-	-
Sm+Sp	-	-	-	-	-	-	-	193	-	-
V+Sp	-	-	-	-	-	72	-	-	-	-
VN	-	-	-	-	562	-	-	-	-	-
Total	384	888	-	-	745	72	119	193	174	520

Note. Sp: teacher's speech; Bb: blackboard; P: printed paper; R: reagents and glassware; Se: slide projection; Sm: simulation; V: video; VN: video with narration; (-) absence. Sp alone denotes that the resource is not available to the external visual field. The absence of combinations with Sp denotes the predominance of resource referentiality by pupils. In VN, the referentiality is made through narration.

The Time Utilisation with Visualization Process in Chemistry

The pre-service teachers' speech in TLS2 and TLS3 presented a predominance of verbal conceptualisations in the submicro domain (493 and 213 sec.) over those of the macro domain (222 and 129 sec.). Verbal conceptualization in both domains also occurred in TLS2 and TLS3. The values of time spent were close to or even almost equal to the verbal conceptualizations in the macro domain, as shown in Table 6.

Table 6

The Verbal Conceptualisation of the Macro and Submicro Domains

Teaching-learning sequences	Verbal conceptualization		
	M	S	MS
		Time (s)	
TLS2	222	493	223
TLS3	129	213	103

This tendency to emphasise conceptualisations in the submicro domain as opposed to the macro domain was also seen in TLS2 and TLS3, when the set of symbolic, iconic, and multiple chemical representations were considered (Table 7). Although in TLS3, conceptualizations occurred in the macro domain during the exploration of symbolic (8 sec.) and multiple (49 sec.) representations, these explorations were not enough to shift time to a predominance of the macro domain. Similarly, in TLS2, some of the time used to explore the visual resources of the experiential domain was used for conceptualization in both domains (51 sec.), not being restricted to the macro domain.

Table 7

The Time Spent on Conceptualisations as a Function of the Type of Visual Resource

Teaching-Learning Sequences	Chemical visual resources											
	Exp			*Sym*			*Ico*			*Sym+Ico*		
	M	S	MS	M	S	MS	M	S	MS	M	S	MS
						Time (s)						
TLS2	222	0	51	0	493	172	-	-	-	-	-	-
TLS3	72	0	0	8	0	0	0	88	103	49	125	0

The results presented in Table 8 show that TLS2 and TLS3 used part of the available time for the provision of at most four types of pupils' actions focused on the visualisation process. No time was allocated for students to discuss among themselves and establish the relationship between representations created by them, and an observed phenomenon and object of explanation (D). In addition, no time was allowed for the identification of limitations of the representations created in comparison with the model or the canonical representation to produce a new and reformulated representation (RR), nor was there time for paper-and pencil-tasks for pupils to relate representations in different chemistry domains (R).

Table 8

Pupils' Actions in Visualisation Strategy

Teaching-Learning Sequences	Pupils' actions						
	Observe (OP)	Elaborate and externalize (EE)	Discuss (D)	Observe the canonical visual model/representation (OM)	Reflect and review (RR)	Relate (R)	Adapt (A)
				Time (s)			
TLS2	132	278	-	653	-	-	834
TLS3	72	-	-	193	-	-	-

The absence of these actions was expected, since the mandatory use of a predetermined visualisation strategy was not linked to TLS planning. These accord with the objective of the study, which to extract pedagogical practice characteristics from approaches using time with visual resources, which presupposes the free choice of teaching approaches and activities. In an opposite situation, the external influences of these conditioning factors would be more easily explored than the pupils' thoughts and authentic choices.

Thus, TLS2 showed that the set of students' actions had a total time of 1,897 sec., while in TLS3 the total assured time was only 265 sec. A greater variety of students' actions also occurred in TLS2 (OP, EE, OM, A), with only two types of actions occurring in TLS3 (OP, OM). While in TLS3, iconic chemical representations were used through interactive simulations (particulate model of matter), in TLS2 only symbolic chemical representations (flat structural formulas) were used through P, Se, and Bb, as shown in Table 7. The use of dynamic visual resources was not associated with the provision of a set of actions to increase the students' engagement with CVR, nor did it produce the highest time values for verbal conceptualisation in the submicro domain in both the macro and submicro domains.

In general, an increased amount of time allocated to the students' autonomous work with CVR and their location in an articulated set of actions positively coincided with increased available time for iconic and symbolic chemical representations at the social level in the classroom, for conceptualisation in the submicro domain, and for discursive movements stimulating the transition between the macro and submicro domains of chemistry.

Discussion

The results showed that TLS3 used dynamic visual resources as simulation (Sm) but was restricted to active observation and mediation with speech, in observe the canonical visual model/representation action (OM). This simulation was used to explain the phenomena previously seen on video (V) in the observe action (OP), i.e., observe a phenomenon or its representation as a conceptual target of chemistry. Some studies have indicated that pupils' actions criticising dynamic resources, comparing and contrasting conflicting resources, and criticising and reflecting on guiding questions, can foster substantial conceptual gain and promote connections between the macro and submicro domains (Akaygun & Adadan, 2019; Chang & Linn, 2013; Kelly et al., 2017). This suggests the time utilisation with more kinds of pupils' actions than just using it for observation actions of the visual resource in class.

In contrast, TLS2 used static visual resources, supported by slide projection (Se) and printed paper (P), being inserted in more students' actions, namely: OP, elaborate and externalize a representation that explains an observed phenomenon (EE), OM and adapt and externalize a representation to explain another phenomenon similar to a previously observed phenomenon (A). In this case, the use of chemical representations was closer to a proficient investigative approach, in which, according to Philipp et al. (2014), the pupils often use representations provided by the teacher, translate a representation of a concept into another type of representation, and use representations to explain chemical concepts, but do not debate about the scope and limitations of the representations.

The iconic aspects of the chemical representations also did not include the verbal exploration of meanings in the submicro domain. In TLS2, flat structural formula symbolic representations were inserted into greater time intervals for verbal conceptualisations in the submicro domain, and for interactions promoting the transition between the macro and submicro domains when compared to the use of multiple representations (Sym + Ico) in TLS3 (Table 7). According to Taber (2013), this exemplifies the ambiguity of symbolic values that allow them to simultaneously reference both domains in the same representation, reinforcing the role of the teacher in stimulating the verbal exploration of the relationships between domains. Thus, conceptual understanding in chemistry includes the ability to represent and translate chemical issues using macroscopic, sub-microscopic, and symbolic representational forms and it could be supported by teachers (Santos & Arroio, 2016).

The results showed a predominance of the use of time for verbal interactions in TLS2 and TLS3 that referenced the submicro domain compared to the macro domain (Table 6). Under the same research conditions, the other two teaching-learning sequences, TLS1 and TLS4, analysed and reported in another article, showed a predominance of verbal conceptualisations in the macro domain of 157 sec. and 222 sec., respectively, being associated with the lowest amounts of time for verbal conceptualisations in the submicro domain, 31 sec. and 64 sec., respectively (Silva & Arroio, 2021).

This discrepancy is consistent with Wu (2003), who showed that reasoning in the submicro domain tends to be provided and instigated by the teacher. The negotiation of representational meanings is critical for deep conceptual understanding, in which the teacher explicitly guides students in recognizing attributes and interpreting representations (Nitz et al., 2014; Waldrip & Prain, 2013; Waldrip et al., 2010). Research on submicroscopic representations has found that their implementation and fluent use is also a function of practice during learning experiences (Hinze et al., 2013) and requires explicit instruction to support learners in directly recognising the informational value of these representations (Ferk Savec et al., 2016; Hrast & Ferk Savec, 2017).

TLS2 and TLS3 showed considerable amounts of time being used for verbal discourse, which ranged between the macro and submicro domains, with values close to those of the macro domain (Table 6). These results are highlighted when compared with data on the other didactic sequences (TLS1 and TLS4), respectively, 28 sec. and the absence of this type of verbal interaction (Silva & Arroio, 2021). This active character of pre-service teachers in the submicro domain and the transit between domains reinforce the view that that the availability of visual resources alone does not assure the mobilisation of their representational and conceptual meanings; according to Santos & Arroio (2016), the teacher's practice will also determine the learners' ability to transit between the meanings of visual representations.

According to Santos and Arroio (2016), pupils moreover face many difficulties in operating at all representational levels in understanding chemistry concepts. Talanquer (2011) pointed out that another cause of difficulties in chemistry understanding is related to learners' inability to interrelate the three levels of representation. Teacher education programmes could provide knowledge and experience for pre- and in-service chemistry teachers to deal more effectively with using visual resources and their time utilisation implications.

The results showed that TLS2 used larger time intervals and greater diversification for pupils' actions (Table 8) than TLS3. This result stands out when compared to the times and diversification found in the other two teaching-learning sequences, i.e., 92 sec. to observe a phenomenon or its representation as a conceptual target of chemistry (OP) and 151 sec. for observing the canonical visual model/representation that explains an observed phenomenon earlier (OM) in TLS1, and 36 sec., for OP in TLS4 (Silva & Arroio, 2021). Some studies have indicated that, in addition to their interpretation, the active construction of representations is particularly important for learning (Ainsworth et al., 2011), as well as the practice of meta-observation, i.e., when an adequate time is set aside for students to rethink their own designs (Locatelli & Arroio, 2014). These actions also improve the modelling experience since the manipulation of visual representations alone does not necessarily assure the learning of the scientific models involved in them (Talanquer, 2011).

When the results are analysed together (with the data obtained from TLS1, TLS2, TLS3 and TLS4), the increased time and diversification of pupils' actions with chemical visual resources coincided with greater amounts of time spent in transition between the macro and submicro domains; with conceptualisations in the submicro domain; and with the conceptualisation of symbolic representations in the submicro domain in the pre-service teachers' speech.

This positive association, in the context of qualitative research, suggests that it may be promising to approach a temporal differentiation that avoids forming a homogeneous view of time in class. That is, an approach that highlights the different possible ways of time utilisation with each type of chemical visual resources, from active observation of a phenomenon (OP) or a canonical model or representation (OM), through practices of construction (EE) and representational refinement (D, RR), to the transition between representations (R) and their use in new situations (A).

This differentiation can qualify the teachers' practices through the use of time, both with verbal negotiations and with the allocation of pupils' actions for the interpretation, construction, and use of visual representations. The teaching strategies with scientific visualisations that research has been producing can help in this challenge of a more critical and less technical chemistry teacher education, because they demarcate pedagogical specificities and can thus can shed light on the contentious issue of different ways to use classroom time.

The results of this study suggest the relevance of temporal differentiation as a function of the type of visual resource used in teaching practice, as well as in relation to the types of actions offered to learners and the encouragement to transition between different representational levels when chemical visual resources are explored. Visualisation processes in chemistry teaching can be better improved when the teacher considers time, that is, when time management becomes essential in this process.
Regarding issues of how pre-service teachers spend time on thematic TLS practices, it can be noted that there is a concern to diversify the visual stimuli by different teaching resources. But there was no concern regarding the time needed considering the specifics of the type of visual resource, that is, chemical or thematic.

While TLS2 and TLS3 showed the longest time intervals with pupils' investigative actions, verbal conceptualizations in the submicro domain and transitions between domains (macro and submicro), the shortest time values and the least diversification of pupils' actions, as well as the predominance of verbal conceptualizations in the macro domain and the shortest time values for transitions between domains were found in TLS1 and TLS4 (Silva & Arroio, 2021).
These two sets of characteristics of time utilisation with visual chemical resources should also be compared with the time utilisation of thematic resources. In Table 4, is shown that the time utilisation with thematic visual resources (TVR) was 745 sec. (37%) while was 1,272 sec. (63%) with chemical visual resources (CVR), in TLS2. In turn, the values were 520 sec. (48%) with TVR and 557 sec. (52%) with CVR, in TLS3. In the same research context (Silva & Arroio, 2021), it noted that TLS4 used 235 sec. (42%) with TVR and 322 sec. (58%) with CVR. In turn, 1,632 sec. (85%) was allotted for TVR and just 292 sec. (15%) for CVR, in TLS1.

When time is allocated to the pupils' investigative actions involving chemical visual resources, the quality of verbal interactions of pre-service teachers increases without coinciding with a decrease on the time allocated for the thematic images. Since the relative distribution of the time utilisation with visual resources remained close for most of the TLSs, i.e., 37%, 48% and 42%.

This suggests that greater knowledge of teaching strategies in the visualisation field can help in TLS planning that can explore different visual resources and improve learning in Chemistry. That is, an exploration marked by an increase in the quality of the time utilisation with chemical visual resources and in balance with the use of time with visual resources for other purposes (e.g., mediating meanings of a theme). This is in line with the challenges of building and implementing chemistry teaching practices with scientific visualizations that are more integrated into the school curriculum.

There is still a predominance of an intuitive use that needs to be problematised to overcome naive perceptions, in which visualizations have been perceived by teachers as an accessory tool, of secondary importance, and not as part of broader teaching strategies, as identified by Ferreira et al. (2011) and Eilam (2012). In fact, with the increasing availability of visual resources with technological advances, not only the subject of visual resources but also of interrelated time usage needs to be considered in teacher education programmes.

Conclusions

These analyses showed a positive association between increased time for different pupils' actions and increased time in pre-service teachers' verbal interactions in the submicro domain and in the transition between the macro and submicro domains. This association was maintained in a thematic teaching context in which the use of non-chemical visual resources acted as a distractor element in the planning and use of chemical visual resources in teachers' teaching-learning sequences, suggesting that the critical incorporation of visualisation strategies (meta-visualisation), or some of its aspects, in the teacher's practice can help overcome its function as a mere didactic resource with an auxiliary teaching function.

Time is one of the structuring dimensions of the classroom environment. Raising a discussion about the ways of using the available time with visual resources in chemistry teacher education can be a fundamental way to rethink the accelerated consumption of images that currently characterises the digital society, and also to integrate the theoretical field of visualisations more thoroughly with the school curriculum, especially in teacher education programmes, considering its limits and its possibilities in the formative experiences of learners.

The results of this qualitative research cannot be generalised, as they were obtained from a small sample and should be considered in the context of the development and implementation of thematic teaching-learning sequences. This context is intended to simulate the school environment marked by teachers' choices about the ways to use time to explore different types of visual resources, conveyed in digital or analog technologies and included in different pedagogical functions. In this study, these types were divided into thematic and chemical, and the pedagogical functions of the latter were considered such as different possibilities of pupils' actions.

More specifically, when the results of four TLSs are considered together, this study points to the importance of a more conscious understanding of ways in which these different types of visual resources are exploited in that both a more even distribution of time use and a strong emphasis on time use in favour of thematic visual resources was observed. In the same vein, this balanced distribution coincided with a higher quality of pre-service teachers' use of speech and with a greater allocation of time for pupils' actions when using specifically the visual chemical resources, which is fundamental for the development of representational and conceptual competencies.

These indications are relevant precisely because scientific visualisations are not an end in themselves; they cannot be seen as a secondary tool for isolated use, but should be integrated in a harmonious way with the other curricular activities, which possibly leads them to a certain competition for the use of time with other resources in the classroom.

Based on these considerations, further studies could help answer questions such as: Have teacher education courses in chemistry provided systematic reflections on the use of visualisations from the temporal contradictions that emerge in the pedagogical practice of future teachers? How do pre-service teachers perceive the use of time when chemical visualisations are explored in the classroom? To what extent can the problematisation of time itself, during the planning stages and in teaching practices, provide an efficient scaffolding to gradually and contextually present the broad and diverse theoretical assumptions of the research field on visualisations?

Limitations of the Study

The focus of this study was placed on pre-service teacher practice. In doing so there is a relative decrease in obtaining in-depth data about pupil learning and about the visual recourses (visualisation objects) themselves. The short intervention (workshops) of two days does not allow for robust conclusions about representational and conceptual pupils' learning in Chemistry; other more longitudinal studies could generate information about this dimension.

The high school students came from different schools and classes. These differences did not compromise the realisation of previously planned activities. However, since the focus was on pre-service teachers our results can be extended in the future with data from the implementation of thematic TLS by different groups of pre-service teachers for the same high school class.

A second aspect lies in the fact that planning thematic TLS is a task that requires more time and work effort. To mitigate this influence, the planning and implementation was done in groups of up to four pre-service teachers. Because of this, both the planning of the forms of time use was the synthesis of negotiated points of view and the distribution of time use in teaching practice was also operated collectively. Studies with planning and teaching practices conducted by only one pre-service teacher could complement these results.

Finally, the early mentioned infrastructural and temporal "boundary conditions" contributed to the effectiveness of the previously prepared plans, which were later analysed. The results pointed out in this research may differ from those obtained from pre-service teachers' teaching practices in a real school environment, with its different possibilities and limitations.

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Appendix A

Narrative Structure Overview of the TLS2 (Day one).

Narrative	TP	Time span	Synthesis of the activities
		0:00:00,0	
Introduction	Prob	0:00:11,0 0:00:54,6	Questions: Do you know any traditional knowledge? Has your family inherited any traditional knowledge that is related to chemical knowledge? Student's actions: oral discussion. Didactic resources: blackboard.
	Expl	0:00:54,7 0:04:31,6	Student's actions: oral discussion.
Development	Avai	0:04:31,7 0:21:58,0	Stimuli provided: Process of producing *carne seca* [jerked beef] and the use of teas for medicinal purposes illustrated by slides. Then, exhibition of two edited videos showing the extraction of black dye from the *jenipapo* (fruit of a native tree to the Amazon and Atlantic Forest.) performed by indigenous tribes using *tipiti* (squeezer of braided straw) and sociological aspects of ethnoknowledge, as well as, the importance of pigments in scientific research. Student's actions: oral discussion. Didactic resources: multimedia projector and blackboard
	Prob	0:21:58,1 0:24:27,2	What is the most efficient way to obtain pigments from a natural product? Didactic resources: blackboard.
	Expl	0:24:27,7 1:10:56,0	Task: Explore, design and test a procedure that best extracts pigments from samples of mate tea, beets, spinach leaves, turmeric root, and annatto seeds. Student's actions: observation and manipulation. Didactic resources: Vegetable oil, ethyl ether, acetone, hexane, glycerol, ethyl alcohol, water at room and hot temperature, glassware and utensils. Papers, brushes and white string to be dyed.
	Avai	1:11:12,2 1:17:03,3	To provide scientific ideas about the polarity of molecules and the types of intermolecular interactions (hydrogen bonding, dipole-dipole, dipole-induced) using seven chemical structural representations of the solvents used in the extraction experiment. Didactic resources: blackboard.
	Avai	1:17:19,7 1:18:49,3	To provide scientific ideas about the polarity of molecules using five extraction products for annatto with different solvents and a chemical structural representation of bixin. Didactic resources: multimedia projector, blackboard and test tube solutions.
	Prob	1:18:50,3 1:23:03,0	Task: Propose an explanatory model for the different results observed in the extraction procedures performed using the concepts of molecular polarity and the molecular representations of the solvent and pigment substances discussed in this lesson. Didactic resources: multimedia projector, blackboard and test tube solutions.
	Expl	1:23:03,5 1:27:40,9	Student's actions: paper-and-pencil task. Didactic resources: multimedia projector, blackboard and test tube solutions.
	Apr	1:27:43,0 1:39:24,5	Resumption of teaching the concepts of molecular polarity and intermolecular interactions based on the students' answers and supported by pictures of mate tea, beet, spinach, annatto, turmeric, by structural representations of melanin, betaine, chlorophyll, bixin, curcumin and the molecular representations of the solvents used.
		1:39:24,6 1:52:11,4	Practical work: The students dyed the white string with the solutions obtained in their extraction experiments. Homework: An internet search on the *biopiracy* subject was requested.

Note. Teaching purposes (TP); Opening up the problem (Prob); exploring and working on students' views (Expl); make scientific and/or thematic ideas available (Avai); guiding students to work with scientific or thematic ideas and supporting appropriation of meanings (Apr); guiding students to apply, and expand on the use of, the scientific or thematic view, and handing over responsibility for its use (Eval); and maintaining the development of the scientific and thematic story (Main), adapted from Mortimer and Scott (2003, pp. 25-26).

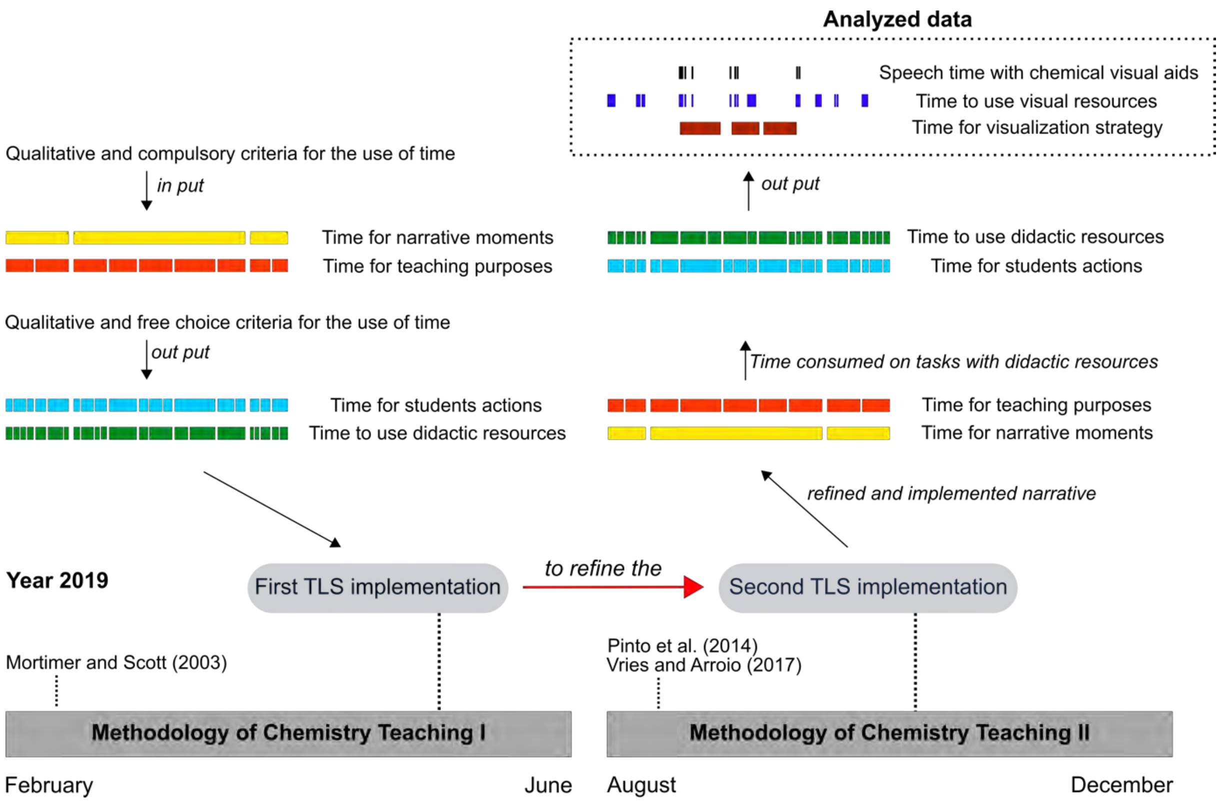
Narrative Structure Overview of the TLS2 (Day two).

Narrative	TP	Time span	Synthesis of the activities
Development	Main	0:00:00,0 – 0:06:55,0	Recap of the main scientific and thematic ideas addressed in previous lesson.
	Eval	0:06:56,2 – 0:20:49,4	Task: Propose and describe in written form a procedure that best extracts the pigment from the purple onion peel using the chemical concepts studied in this class and analyzing the structural representations of solvents such as water, ethanol, ethyl ether, oil and acetone and that of an anthocyanin. Student's actions: paper-and-pencil task. Didactic resources: printed paper with image and chemical structural representations.
	Expl	0:20:49,5 – 0:30:43,0	Task: Present orally the description of the elaborated procedure and argue with chemical concepts. Then participate in a collective discussion with the whole class. Student's actions: oral discussion.
	Avai	0:30:44,0 – 0:46:40,5	The resumption of scientific ideas using solid samples of the natural products (extraction substrates), the extracts (solutions) prepared in the previous lesson, and their respective dyed string. Then reading of labels of commercial products with emphasis on the use of essential oils by industry. Next, observation of the functioning of a vapor steam distillation system for clove extraction. Student's actions: observation and manipulation.
	Expl	0:49:12,3 – 1:05:03,0	Elicitation of students' ideas about the term biopiracy and the information found in the internet search.
	Avai	1:05:03,1 – 1:32:09,1	Exposure of main ideas related to biopiracy using the life story of the first Brazilian indigenous woman to obtain a Master's Degree in Law. Then, carry out the reading of four newspaper articles that portrayed real cases of biopiracy accusations in Brazil. Student's actions: oral discussion and text reading. Didactic resources: printed paper and multimedia projector.
Conclusion	Eval	1:32:09,5 – 2:00:38,1	Task: Elaborate and orally present your arguments about a hypothetical legal dispute about biopiracy. Create arguments to defend the defendant company (social or economic importance of ethnoknowledge) and also to defend the rights of traditional groups over their knowledge. Student's actions: oral discussion and text reading. Didactic resources: printed paper.
		2:01:44,3	Closing of the workshop.

Note. Teaching purposes (TP); opening up the problem (Prob); exploring and working on students' views (Expl); make scientific and/or thematic ideas available (Avai); guiding students to work with scientific or thematic ideas and supporting appropriation of meanings (Apr); guiding students to apply, and expand on the use of, the scientific or thematic view, and handing over responsibility for its use (Eval); and maintaining the development of the scientific and thematic story (Main), adapted from Mortimer and Scott (2003, pp. 25-26).

Appendix B

Research Framework



Appendix C

Teaching Resources Category and Its Codes

Codes	Inclusion rule
Reagents, glassware, and equipment (R)	The time interval in which resources and materials are made available and referenced through speech in discursive interactions between pre-service teachers and pupils or made available in interactive or non-interactive activities of pupils during the unfolding of the thematic teaching-learning sequence.
Video with narration (VN)	
Video (V)	
Pre-service teacher's speech (Sp)	
Simulation (Sm)	
Slide projection (Se)	
Blackboard (Bb)	
Printed paper (P)	

Appendix D

Visual Resource Category and Its Codes

Codes	Inclusion rule
Experiential domain (Exp)	This code measures the amount of time in which objects, phenomena, or their macroscopic scale representations associated with chemical meanings are made available and/or referenced by the pre-service teachers’ and/or by the students’ speech or through narration.
Symbolic representations (Sym)	This code measures the amount of time in which the symbolic representations of chemistry are made available and/or referenced by the pre-service teachers’ and/or by the students’ speech or through narration.
Iconic representations (Ico)	This code measures the amount of time in which iconic representations of chemistry are made available and/or referenced by the pre-service teachers’ and/or by the students’ speech or through narration.
Thematic visual resources (T)	This code measures the amount of time in which any types of non-verbal visual resources associated with the meanings of the topic are made available and/or referenced by the pre-service teachers’ and/or by the students’ speech or through narration.