Received: 30 August 2023 | Revised: 3 October 2024 | Accepted: 17 October 2024

DOI: 10.1002/tea.22001

RESEARCH ARTICLE

JRST | WILEY

Evidence of graphical literacy in students' oral presentations: An example from undergraduate chemistry education

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Funding information
Fundação de Amparo à Pesquisa do Estado de São Paulo, Grant/Award Numbers: 2018/23809-3, 2020/14789-9; Conselho Nacional de Desenvolvimento Científico e Tecnológico, Grant/Award Number: 304974/2020-0

Abstract

In the context of scholarly and scientific discourse, students often have to deal with graphic-visual modes of communication, which requires their ability to comprehend and utilize inscriptions, that is, scientific visual representations, to convey information effectively—what we call graphical literacy. Despite its pivotal role for training scientists and facilitating scientific communication, there is a lack of resources for assessing the graphical literacy of undergraduate students during oral presentations (OPs), a common assignment in post-secondary educational contexts. This study addresses this gap by investigating the graphical literacy of first-year chemistry undergraduate students by analyzing the inscriptions they used during multimodal OPs designed to display the resolution of a problem posed through interrupted case studies. Our results are presented as claims that highlight how students' engagement with inscriptions in OPs makes evident their graphical literacy. These findings have significant implications for educators, providing guidance for assessing graphical literacy and the effective use of inscriptions in OPs.

KEYWORDS
chemistry education, graphical literacy, inscriptions, oral presentation, post-secondary education, scientific communication

1 | INTRODUCTION

Scientific literacy was highlighted in a way rarely seen in human history during the Covid-19 pandemic, when the dissemination of scientific research by mass media became a daily event (Sotério & Queiroz, 2022). This widespread sharing of scientific information also drew attention to the importance of scientists' communication skills, not only when addressing peers and funding agencies, but also with the general population and policymakers (Wirz et al., 2022).

The development of scientific communication skills is often promoted in university courses. This is a challenging task, as the regular content in science-related programs is usually extensive and adding courses to foster the learning of scientific communication skills may not be straightforward (Rootman-le Grange & Retief, 2018). Indeed, the ideal option is to design courses specifically aimed at improving skills related to scientific communication. However, what is commonly observed is the attempt to develop communication skills as part of existing scientific discipline courses (e.g., chemistry, physics, and biology), where students prepare reports and present seminars based on experimental data (Oliveira & Queiroz, 2015). The main advantage of courses designed specifically to foster communicative skills is the greater amount of time the students have to dedicate to the study of different aspects of scientific communication, such as conventions of scientific writing, discussions pertinent to the credibility of sources of information for the general public, ethical aspects of science, and preparation of seminars, posters (Oliveira & Queiroz, 2015), and multimodal oral presentations (OPs).

In formal academic contexts, scientific information is communicated through multiple modes, including verbal, gestural, and graphic-visual modes. Indeed, several types of graphical representations other than text (e.g., graphics, photographs, maps, diagrams, drawings, equations, and tables), to which we refer as *inscriptions*, are commonly used to present data and findings, organize information, and explain phenomena in scientific presentations. Numerous studies have demonstrated the intrinsic connection between inscriptions and science and their essential function (e.g., Latour & Woolgar, 1986; Lynch & Woolgar, 1990), with inscriptions acting as cultural artifacts of the scientific community. Given their pivotal role in science, effective use of inscriptions in scientific communication requires both scientists and students to develop graphical literacy, that is, an understanding of how to interpret and utilize inscriptions.

In this study, we report on our investigation of the graphical literacy of first-year chemistry undergraduate students by analyzing their use of inscriptions during multimodal OPs designed to display the resolution of a problem posed through interrupted case studies (Herreid, 2005). In this scenario, students were engaged in activities typical of authentic scientific knowledge production, including framing hypotheses, designing investigations to test hypotheses, argumentation, and reading/interpreting/producing inscriptions, as part of solving case studies that consisted of narratives about individuals who faced dilemmas concerning the contamination of water resources.

The analysis of students' OPs led to the elaboration of claims identifying instances where skills related to the use of inscriptions in OPs serve as evidence of their graphical literacy.

Hence, this study sought to answer the following research question: How is graphical literacy evident in students' multimodal OPs, and what evidence can be used to assess it? The claims we made in this study provide educators with means to assess students' graphical literacy during multimodal OPs, a widely used assignment in post-secondary education.

2 | THEORETICAL FRAMEWORK

In this study, we build on Wolff-Michael Roth's work on *use of inscriptions as social practices* (Roth et al., 2005; Roth & McGinn, 1998), according to which the term "inscriptions" refers to representations that exist in a material form (e.g., paper, screens, and projections) and are specifically designed to depict scientific objects and phenomena. This distinguishes inscriptions from "representation" and "visual representation," which can also refer to mental representations, which are not directly accessible (Roth & McGinn, 1998). This distinction allows us to differentiate our research focus from studies in science education that address both internal and external visual representations (e.g., Gilbert, 2005).

Grounded in semiotics, anthropology, and critical phenomenological hermeneutics, Roth et al. (2005) conceptualize inscriptions as texts and complex signs that do not speak for themselves. Instead, meaning-making occurs through the explicit and implicit elements within the inscriptions, influenced by the context and specific domain in which they are utilized, as well as the cultural conventions that govern their interpretation. The product of this process is the relationship between the inscription and the phenomenon it represents, that is, its meaning, which is not fixed but shaped by these social and cultural conventions. This relationship is learned through participation in practices that involve the collection, combination, and dissemination of inscriptions. As a result, students' ability to interpret inscriptions depends on their familiarity with these domain-specific practices.

Graphical literacy, also referred to as graphicacy or graph sense, is defined by Roth et al. (2005) as the knowledgeability related to comprehending, selecting, utilizing, drawing, combining, communicating with, and translating between inscriptions. In their view of inscriptions as a social practice, meaning is not attributed to individual cognitive processes but is instead collectively negotiated through cultural conventions and shared practices within a community. Consequently, graphical literacy skills are seen as a product of these social constructs, underscoring the importance of students' experiences with inscriptions (Roth et al., 2005). Rather than focusing on the retention of more information through inscriptions, this conception emphasizes the evaluation of whether the information and practices associated with inscriptions are meaningful and contribute to broader scientific literacy, aligning with broader perspectives from literacy studies (e.g., Ludewig, 2018). Given the pervasive presence of graphs and visual data in both academic and everyday contexts, graphical literacy is essential not only for scientific understanding but also for navigating visual information in daily life.

Since understanding an inscription depends on a student's familiarity with the inscription practices within a specific domain, the development of graphical literacy can be viewed as the degree to which teaching actively immerses students in them. Inscription practices are the situated activities that allow individuals to apply and develop their skills related to the use and interpretation of inscriptions, that is, their graphical literacy. Simply exposing students to inscriptions through textbooks or lectures is insufficient. To foster graphical literacy, students must engage in activities that reflect the use of inscriptions within the scientific community and the particular domain of study. Roth et al. (2005) advocate for pedagogical approaches that guide students through reading, interpreting, selecting, producing, transforming, and communicating with inscriptions to support scientific arguments. This approach underscores the rhetorical and scientific significance of inscriptions.

Additionally, students should be encouraged to critically examine the construction of different forms of inscriptions and consider what they include or omit. This critical reflection involves questioning why certain features are highlighted in a given inscription and how these choices influence their understanding of the phenomenon. By integrating this critical reflective approach, educators enable students to engage more deeply with scientific inquiry, moving beyond passive acceptance of visuals as objective reality. In doing so, students cultivate a form of graphical literacy that not only enhances their technical inscriptional skills but also fosters an understanding of the epistemological and political dimensions of inscriptions and inscription practices, promoting a more sophisticated and reflective approach to scientific reasoning.

By recognizing that reading and interpreting inscriptions is context-dependent, we also acknowledge that the use of inscriptions for communication purposes similarly relies on context, which, in oral genres, involves an awareness of participants, purpose, genre structure, and language resources (Dolz et al., 2004). Thus, communicators can choose resources to effectively guide their audience in interpreting the inscriptions and accompanying utterances, particularly when engaging with non-expert audiences. Additionally, effective use of inscriptions in scientific communication involves seamlessly integrating the graphic-visual mode with other modes of communication, such as oral and written discourses, as well as gestures. Engaging students in science activities, from obtaining and analyzing data to communicating findings to specialists or non-experts, involves coordinating an understanding of the science domain with an understanding of the representational language of inscriptions (Round & Campbell, 2013).

3 | GRAPHICAL LITERACY IN CHEMISTRY EDUCATION

The examination of the visual and contextual features of inscriptions in textbooks and other media is a prevalent focus of studies in the area of science education and chemistry teaching (Vojíř & Rusek, 2019), representing the first of four foci of research on external visual representations and students' learning, as outlined by Gebre and Polman (2016). Notably, in Western culture, textbooks serve as the primary source through which students encounter inscriptions in classrooms (Bowen & Roth, 2002). Therefore, the way the inscriptions are conveyed in textbooks and other curriculum materials is significant for inscription practices and the development of graphical literacy. By discerning the strengths and weaknesses of inscriptions, educators can devise strategies to address deficiencies while leveraging their pedagogical strengths to enhance instructional practices and students' graphical literacy (Silva de Lima et al., 2022).

Research concerning inscriptions in chemistry textbooks, whether of K-12 or higher education, predominantly centers on two key aspects (Silva de Lima et al., 2022). The first aspect pertains to the meaning-making process associated with inscriptions and their visual features (e.g., Barradas-Solas & Gómez, 2014; Han & Roth, 2006; Rozentalski & Porto, 2015), highlighting the processes of structuring inscriptions and support texts, transposing, and connecting inscriptions with text (Han & Roth, 2006). Moreover, inscriptions in textbooks, especially the ones portraying chemical entities, often create the impression for students that they are witnessing the genuine visualization of those entities and their interactions (Barradas-Solas & Gómez, 2014; Han & Roth, 2006). This underscores the need to differentiate between representation and represented entities, which is essential for elucidating the aspects of the latter that inform the construction of the former (Rozentalski & Porto, 2015).

The second key aspect in inscription research in chemistry textbooks is their pedagogical functions within the text (Silva de Lima et al., 2022). This aspect involves examining various factors such as inscription frequency, types, and associated textual elements like captions, labels, and indexation (e.g., Gkitzia et al., 2011; Goes et al., 2020; Nyachwaya & Gillaspie, 2016; Slough et al., 2010; Upahi & Ramnarain, 2019). The significance and prevalence of inscriptions in scientific texts underscore the essential nature of graphical literacy in the construction of scientific knowledge, rendering it a fundamental competence for students to acquire during their formative years (Postigo & López-Manjón, 2015).

The second focus is on the difficulties students encounter when learning from inscriptions across different grade levels, while the third focus is on how various inscriptions can aid students' understanding of specific subjects. These research foci are underscored by extensive literature on the multi-representational levels of chemistry (macroscopic, submicroscopic, and symbolic - see, for example, Gilbert & Treagust, 2009), with the aim of elucidating students' capacity to comprehend, utilize, generate, integrate, and translate between these levels when learning chemical concepts and solving problems (e.g., Chandrasegaran et al., 2008; Corradi et al., 2015; Davidowitz et al., 2010; Farheen & Lewis, 2021; Gkitzia et al., 2020; Güven & Uyulgan, 2021; Hilton & Nichols, 2011; Rappoport & Ashkenazi, 2008; Thomas, 2017; van der Meij & de Jong, 2006; Wu et al., 2001).

However, simply incorporating inscriptions into the science classroom or engaging students in authentic scientific practices does not inherently ensure effective learning or the cultivation of their graphical literacy (Guo et al., 2020). Therefore, numerous scholars advocate for the explicit instruction of visual language and inscription practices (e.g., Ardac & Sezen, 2002; Chiu & Linn, 2014; Gebre & Polman, 2016; Hilton & Nichols, 2011; Lawrie & Bartle, 2013; Thomas, 2017; Witkow et al., 2022; Wu et al., 2001). These studies constitute the fourth focus of research in inscriptions, according to Gebre and Polman (2016): Studies aimed at enhancing learners' graphical literacy by actively involving them in producing inscriptions. Both Chiu and Linn's (2014) and Davidowitz et al.'s (2010) findings demonstrated the significant positive impact of exposure, explicit instruction, and feedback on inscription use on students' performance.

In line with the perspective presented in these and other studies (e.g., Dori & Sasson, 2008; Kindfield & Singer-Gabella, 2010; Prain & Tytler, 2012), educators are encouraged to invest time and effort in meaningful discussions with their students regarding the interpretations and implications of the inscriptions employed within the classroom setting, and the role that inscriptions play in the construction and communication of scientific knowledge. This explicit instructional approach not only enhances students' graphical literacy but also deepens their understanding of the nature of science (Prain & Tytler, 2012), elucidating how knowledge claims can be formulated, justified, and conveyed through diverse forms of inscriptions, promoting more effective learning outcomes.

Yet, as pointed out by Kim and Jin (2022), few studies are dedicated to examining communication through inscriptions or their rhetorical usage in multimodal genres commonly employed in scientific discourse. These genres encompass OPs, videos, poster sessions, seminars, and similar formats (e.g., Lawrie & Bartle, 2013; Silva de Lima & Queiroz, 2021). For instance, Lawrie and Bartle (2013) involved first-year undergraduate students fan introductory chemistry course in the production of short vlogs focusing on the properties of a substance personally relevant to students. Visual aids were encouraged in the vlogs. Students who integrated physical models and hand gestures with the inscriptions included on their vlogs provided more advanced explanations compared to those who relied solely on static images obtained from online sources.

In a study of multimodal OPs based on peer-reviewed articles, Silva de Lima and Queiroz (2021) examined how the meaning-making process unfolds when communicating with inscriptions during OPs. Being aware of the specificity of the communicative context of OPs (Dolz et al., 2004) and deliberating on the use of inscriptions in this context demand graphical literacy skills. For instance, in situations where the audience lacks familiarity with the topic under discussion and, consequently, with the inscriptions typically associated with it, presenters must carefully select inscriptions to illustrate concepts or present data and results. Moreover, they need to provide guidance to the audience on how to interpret and engage with these inscriptions (Silva de Lima & Queiroz, 2021).

Nonetheless, there remains a significant gap in research specifically focused on graphical literacy in OPs. Existing studies focus on students' competencies in using and interpreting inscriptions within reading and writing contexts, relying on resources such as protocols, interviews, questionnaires, rubrics, and other diagnostics to assess graphical literacy (e.g., Chandrasegaran et al., 2008; Hilton & Nichols, 2011; Wu & Krajcik, 2006). To our knowledge, there are no resources reported in the literature to analyze and assess the graphical literacy of undergraduate students during multimodal OPs. This lack of operational models for assessing graphical literacy during OPs makes it difficult to promote and evaluate students' graphical literacy skills in these situations. Thus, there is a compelling need to explore the potential of multimodal communicative genres in fostering and/or providing evidence of graphical literacy, which can offer valuable insights into effective instructional strategies in science education. Our study aims to contribute to the research on graphical literacy in OPs by providing evidence-based insights into how this literacy is demonstrated in multimodal scientific communication genres, while also responding to the lack of resources for assessing graphical literacy in OPs. Specifically, we propose claims about the evidence of graphical literacy in students' OPs, analyzing situations that could serve as a foundation and framework for developing assessment tools for students' engagement with inscription practices and graphical literacy.

4 | METHODS

4.1 | Study context and participants

The OPs analyzed in this study were a culminating assignment in two sessions of a course on scientific communication to first-year undergraduate students in the Bachelor of Chemistry program at the São Carlos Institute of Chemistry, University of São Paulo, Brazil. Students in this program transitioned directly from high school, therefore, their experiences with inscriptions were varied. In this course, students were exposed to specific and explicit instructions on how to select and use inscriptions appropriately during scientific oral and written presentations. For the last assignment of the course, students were given three case studies based on published peer-reviewed research articles in chemistry, reporting on the effects of mining and other human activities on water resources and human health. The case studies can be accessed at https://gpeqsc.iqsc.usp.br/estudos-de-caso-interrompidos/. A full description of the course activities and an analysis of the effectiveness of the interrupted case study method in teaching and learning in post-secondary chemistry courses can be found in Silva de Lima et al. (2023).

In each one of the two sessions of the course, students were divided into six groups of four to five individuals. In each course session, two groups solved the same case study. Therefore, in the two sessions of the course, 12 groups were formed (six per course session), with four groups (two per course session) solving each case study. The case studies were divided into four parts. In Part I, the characters, the problem, and a map of the region under investigation were presented. Based on this information, the groups formulated hypotheses about the origin of the problem and proposed a research question. In Part II, information about human activity in the region was provided. Students were asked to outline an experimental procedure to test their hypotheses based on the demarcation of sampling points on a map and the choice of equipment for instrumental analysis. In Part III, the characters' choices for the sampling points, sample preparation, and analytical equipment were shared with students (these were directly from the original research articles from which the case studies derived). Students were invited to compare their chosen procedures with those of the characters and of other groups, justifying their decisions. Finally, in Part IV, the metal concentrations of water resource sediments in the regions were presented in tables, with reference values based on legislation or literature, along with other information about the chemical behavior of specific metals. The groups were then asked to discuss and elaborate alternative representations of the data tables to draw conclusions and evaluate their hypotheses. All group members were required to participate in all course activities for all four parts of the case studies, and students should collaborate on the preparation of the final multimodal OP, although only one group member was the presenter of the OP.

The course instructors provided feedback on students' written responses to the activities in Parts I–IV of the case studies. Moreover, the students were also provided with specific instructions for preparing a 15-min multimodal OP using slides as support material, through which students should communicate their resolution process to the case study. All the OPs took place during the same class, and no Q&A followed the presentations. In a subsequent class, the instructor provided the class with a summary of the resolutions of the case studies as presented during the OPs.

4.2 | Data collection

Given the COVID-19 pandemic, course activities took place remotely through Google Meet and Tidia-Ae. The latter, similar to Moodle and Google Classroom, is a virtual learning environment designed for managing courses and facilitating learning activities. Within this platform, users have access to a range of tools and resources designed to support communication, content distribution, and participant management. The use of these two digital learning platforms during the course allowed for an expansive and detailed record of the complexity of the students' actions and productions during the case study resolution activities, unfolding during six classes, totaling 9 h of recording. We recorded student participation in activities via audio and/or video, written chat, and screen sharing.[1] The Tidia-Ae virtual environment was used to collect students' productions (e.g., written texts and OP slides).

For this study, we selected three out of the 12 OPs produced, as these were the three groups in which all students participated in all activities and all group members consented to participate in this study. These OPs are heretofore referred to as OP-G1, OP-G2, and OP-G3. The three selected OPs were transcribed, focusing on verbal utterances and non-verbal actions. Although the OPs were presented by an individual member of the group, we consider the OPs as resulting from the collective work of all members of the group. That is, we approach the evidence of graphical literacy in these collaboratively designed multimodal OPs not merely as something residing in individuals' minds but as the observable result of a social event which outcomes were produced collectively (Roth et al., 2005).

4.3 | Data analysis

The study adopts a qualitative research approach, and data analysis took place through Interaction Analysis meetings following the precepts of Jordan and Henderson (1995). In these meetings, collaborative analysis of video data takes place through the microanalytical observation of regularities in the actions and processes of meaning production that emerge through the use of speech, texts, gestures, material artifacts, and other multiple forms of recording human social interactions. Interaction Analysis uses repeated viewing of videos to demonstrate a phenomenon, through which the researcher creates a catalog of participants' actions, which helps locate and select events of interest (Jordan & Henderson, 1995). Based on this, the OPs were considered the main event to be investigated, since it is during these presentations that various inscriptions were used to communicate the groups' resolution of the case studies and associated tasks. The types of inscriptions utilized and the number of times these were used during the OPs of each of the three groups that constitute our dataset are presented in Table 1.

During Interaction Analysis sessions, which took place on Zoom, the three authors of this article repeatedly watched the videos of the three selected OPs, using the screen share function on Zoom, requesting to pause the video whenever something significant called their attention so they could propose observations or ask questions about the activity being analyzed. Collaborative analysis sessions are ideally conducted without predetermined codes or categories, which should naturally emerge from the diverse perspectives and interpretations of the social interactions under investigation (Jordan & Henderson, 1995). In our microanalytical observation of the recordings, we focused on describing and identifying how students demonstrated graphical literacy through their use of inscriptions in the OPs. As Jordan and Henderson (1995) recommended, the analysis sessions were recorded and later reviewed by the first author, who then proposed claims about general patterns, explaining the evidence and exceptions to these

TABLE 1 Number of slides and types of inscriptions used in the oral presentations for resolving the case studies.

Group	G1	G2	G3
Number of slides	13	26	33
Number of slides with inscriptions	13	9	18
Types of inscriptions			
Photographs	0	2	1
Iconic drawings	13	4	6
Maps	5	3	9
Flow diagrams	2	1	0
Tables	4	3	6
Graphs	2	0	4
Total inscriptions	26	13	26

claims in subsequent Interaction Analysis meetings, which were also recorded. This also allowed us to maintain an audit trail of our emerging analysis and conclusions. As needed, other documents were screen shared during the analysis meetings (e.g., transcripts of the videos and images of the students' coursework) to make interpretive decisions. This process revealed that, in the OPs we analyzed, graphical literacy became evident through presenter's skills in selecting, producing, and communicating with the inscriptions included in the OPs. Therefore, the product of our interactional analysis is a detailed description of our interpretation of patterns observed in the data—specifically, the students' engagement with inscriptions in their OPs and how this engagement demonstrates their graphical literacy.

5 | RESULTS AND DISCUSSION

From the Interaction Analysis of the OPs, three key skills emerged as central evidence of the students' graphical literacy: inscription selection (choosing inscriptions for specific purposes within the OP), inscription production (creating the inscriptions used in the OP), and inscription communication (employing multimodal strategies to explain content during the OP). Although these three skills are considered separately to report our results, it is important to note that they often appear concurrently, and all three skills require the ability of interpreting ("reading") inscriptions. We developed claims that highlight how students' engagement with inscriptions in multimodal OPs—through selection, production, and communication—demonstrates their graphical literacy. Educators can use the descriptions and interpretations provided in this section as references, recognizing that the situations outlined in our claims are relevant scenarios they may also encounter when assessing undergraduate students' OPs. This alignment can facilitate more targeted evaluations of graphical literacy in their teaching practices. Later, we discuss the value and how these observations lay the foundation for developing assessment tools for graphical literacy in OPs and other multimodal scientific communication genres.

5.1 | Claim 1: Students' graphical literacy is demonstrated in their skill to select inscriptions for inclusions in the OPs

Proficiency in selecting inscriptions necessitates consideration of the concepts they represent, the audience, purpose, and structure of the communicative task, and the domain of knowledge being represented, so that inscriptions that effectively and accurately convey the intended information can be chosen. In the context of OPs, expertly selecting inscriptions may facilitate the sequencing of the information presented, structure the interpretive work of audiences, call attention to specific content in the presentation, and promote understanding of complex scientific phenomena. Choosing an inscription, then, is not merely about the accuracy of the information but also about ensuring it resonates with the specific context and community to which it is presented, aligning with the participants' expectations, goals, and interpretative frameworks. From the Interaction Analysis, our first claim is that students demonstrate graphical literacy through their skill of selecting inscriptions for OPs. This was evident in our data when students:

- Constructed slides using inscriptions available in a template associated with the theme of the OP and
- Used inscriptions to illustrate objects that played a major role in the resolution of the case study.

Among the instructions provided to students for preparing slides to be used in their OP, course instructors mentioned the possibility of using slide templates available online. As a result, the need for groups to invest extensive effort in learning technology can be reduced, while simultaneously enhancing opportunities to incorporate the content that they may wish to share with their peers (Dugan, 2007). All groups opted for using these templates, which already contained graphical elements, such as color blocks and drawings. For example, the slides used by G1 (Figure 1), using the "Chemistry Thesis" template from the Slidesgo website, include several drawings related to chemistry laboratory. In Figure 1a, the drawings of a person wearing personal protective equipment (e.g., a white lab coat and protective goggles) and of standard laboratory glassware are included on the slide. In Figure 1b, there is a drawing of a graduated thermometer; in Figure 1c, we can see a round-bottomed flask heated by flame supported by a ring stand and gloves; and in Figure 1d, a drawing of a microscope. These inscriptions represent equipment commonly found in chemistry laboratories or, in the case of Figure 1d, related more broadly to scientific laboratory equipment.

During the OP, there are no oral or gestural references made to these drawings, which renders them a decorative role (Pozzer & Roth, 2003). That is, the iconic drawings are used with aesthetic purposes related to adding a theme representative of the topic of the presentation and capturing the audience's attention. The students' choice of template with embedded inscriptions

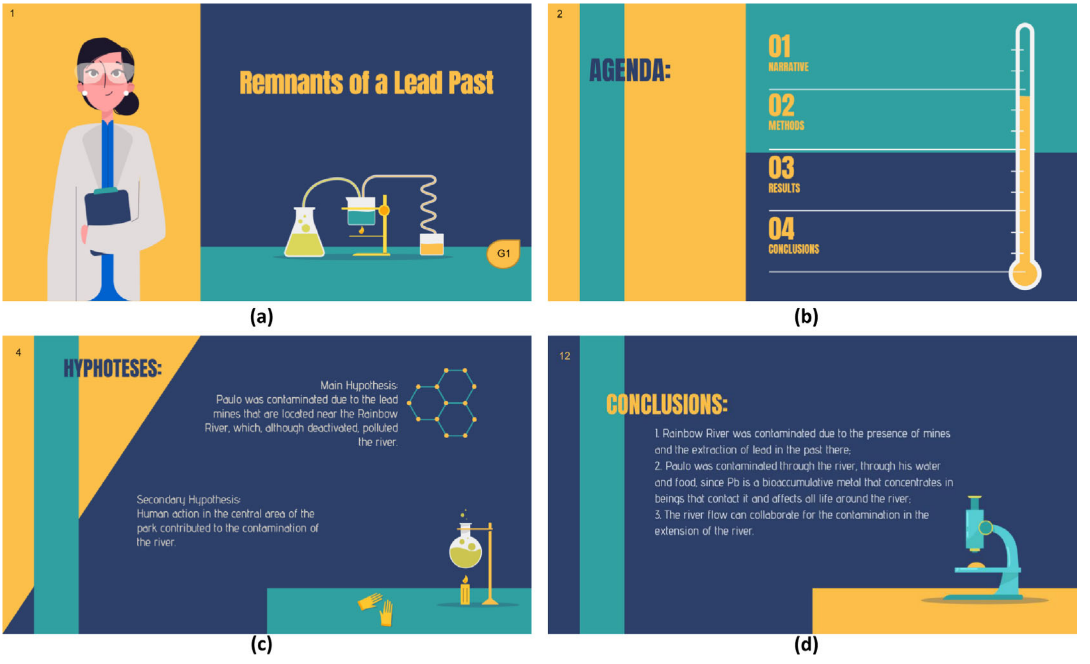


FIGURE 1 Iconic drawings from a slide template used in the oral presentation-G1. (a) Slide 1. (b) Slide 2. (c) Slide 4. (d) Slide 12.

indicates discernment regarding its content and the context (undergraduate chemistry program) in which the inscriptions are being presented. This is evidence of G1 students' graphical literacy skills, as the students' demonstrated understanding of how visual elements can contribute rhetorically to the thematic cohesion and aesthetic appeal of the OP.

During the resolution of the case study, the groups selected and read about instrumental analytical techniques. During the OP-G2 and OP-G3, inscriptions were used to illustrate the group's choice of analytical equipment. Figure 2 exemplifies the use of a photograph to illustrate analytical equipment in the OP-G3.

In Figure 2, the title of the slide reads "Equipment Used" (all texts in the slides were translated into English by the authors). Below it, the text mentions the type of analytical equipment students selected and their justification for selecting this particular equipment. To the right of the text, there is a photograph with the caption "Figure 7. Inductively coupled plasma mass spectrometer (ICP-MS)." Below the picture, the source from which the photograph was obtained is provided as a URL. During the OP-G3, the presenter discussed the merits of the selected equipment without an explanation of its operation. As first-year undergraduate students, these students have not yet delved into the intricacies of instrumental analysis. The inscription illustrates the equipment named in the caption, mentioned orally in the speech, therefore also directly relating to the title of the slide. The photograph is not directly referenced in speech or gesture during the presentation, thus being treated as obviously related to the other elements in the slide (i.e., title, text, and caption). Since its caption names what is to be seen in the photograph, this inscription is categorized as illustrative as per its function in the presentation (Pozzer & Roth, 2003). Moreover, the use of this photograph in this context aligns with Roth and McGinn's (1998) description of characteristics of inscriptions, namely the easy mobility and incorporation in different contexts (the photograph was originally from a laboratory equipment sales website). The incorporation of the photograph from an external source underscores the students' discernment in selecting inscriptions that illustrate an object that played an

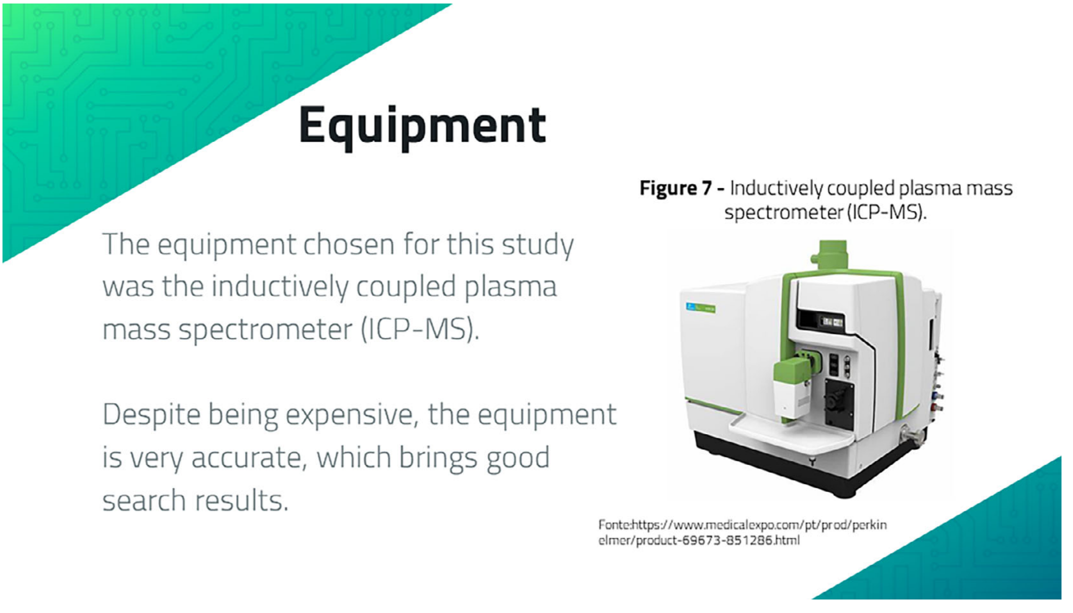


FIGURE 2 Slide from oral presentation-G3 with a photograph.

important part of the case study resolution. The appropriate textual connections between the elements on the slide and on the oral speech, enhancing the presentation's cohesion, demonstrate the students' selection skills, further evidence of their graphical literacy.

5.2 | Claim 2: Students' graphical literacy is demonstrated in their skill to communicate with inscriptions in OPs

Communication with inscriptions in OPs is inherently context-dependent, requiring students to consider the audience's level of expertise, the purpose of the presentation, and the structure of the genre (Dolz et al., 2004), as well as having a solid understanding of the knowledge domain being represented. When addressing non-expert audiences, an essential first step involves guiding the audience through the reading of visual data by identifying key visual features and patterns within the inscriptions. This initial stage lays the foundation for the subsequent discourse, during which students must effectively utilize the identified features of inscriptions to explain phenomena, defend claims, draw inferences, and achieve various communicative objectives, thus potentializing the audience's understanding of the subject matter while simultaneously demonstrating their ability to communicate with inscriptions, which in turn is evidence of their graphical literacy. Through the skillful combination of visual, oral, and gestural modes of communication, inscriptions become dynamic tools that facilitate deeper engagement with the content of the OP. From the Interaction Analysis, our second claim is that students demonstrate graphical literacy through their skill of communicating with inscriptions in OPs. This was evident in our data when students:

- Used inscriptions to help explain concepts linked to the case study theme;
- Used maps to present the selection of sampling points for the resolution of the case study; and
- Associated inscriptions of the same nature to compare experimental procedures and discuss data for the resolution of the case study.

The use of inscriptions to explicitly provide explanation of scientific concepts crucial for the resolution of case studies during the OPs was observed in our dataset only in the OP-G3. Figure 3 illustrates the use of an iconic drawing to explain the concept of bioaccumulation.

During the OP-G3, only the textual elements on the slide in Figure 3 were available initially. The text, together with the oral discourse, qualitatively defined bioaccumulation as the gradual accumulation of substances in an organism from its direct or indirect contact with a source of contamination. Then, the drawing appeared on the slide, in which it is possible to visualize, from left to right, red splotches, a fish with its mouth open in the direction of the splotches, and a person with their mouth open in the direction of the fish. The figure also has the label "Bioaccumulation" and the title "Bioaccumulation diagram."

The selection of the iconic inscription is related to the qualitative nature of the information discussed before it appeared on the slide. Moreover, according to the OP-G3 presenter's statement, "*In* Figure 2, *I showed a bioaccumulation diagram*," it is evident the students selected the inscription to illustrate the concept of bioaccumulation qualitatively. According to Lee and Jones (2018), selecting an inscription to help explain content may indicate that such a resource is seen not only as a playful, decorative, or illustrative element but as a communicative scientific tool. After the image appeared on the slide, the verbal discourse continued on the concept

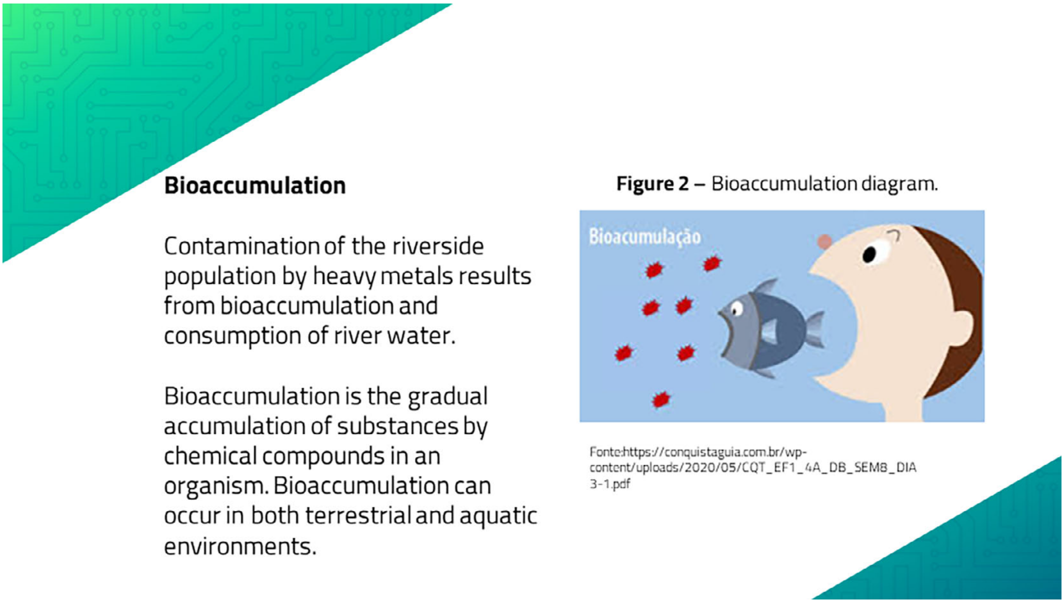


FIGURE 3 Slide from oral presentation-G3 with an iconic drawing used to explain the concept of bioaccumulation.

of bioaccumulation, which then was also grounded on the inscription. Thus, the slide design helps explain a relatively complex concept, encompassing different knowledge in chemistry, ecology, and physiology (Kim & Kim, 2013).

Furthermore, the slide in Figure 3 highlights the inscription communication in OPs. The OP-G3 presenter's speech, "*Here in* Figure 2, *I showed a bioaccumulation diagram, in which there is a little fish that is eating some heavy metal waste*," in association with prominent deictic gestures, draws attention to certain graphic elements (fish and metal waste) and interprets the image as representing a fish ingesting particles contaminated by heavy metals. That is, the group used a multimodal discourse to instruct the audience about how the inscription should be viewed.

Another communicative strategy identified in this OP concerns expanding the meaning of the inscription, allowing it to connect to what was being discussed before its appearance on the slide. At that time, bioaccumulation had been defined as the gradual accumulation of substances in an organism. However, such an accumulation is not necessarily depicted in the inscription. Other studies have noted the challenges students face in locating inscriptions that accurately convey a specific scientific information (Gkitzia et al., 2020; Wu et al., 2001; Wu & Krajcik, 2006) as they may be swayed by visual features, such as colors (Gebre & Polman, 2016). Concerning what was being discussed, the drawing has an information gap, which the presenter filled by stating the following, combined with the gestures illustrated in Figure 4: "*There is a little fish that is eating some heavy metal waste (…) it accumulates, the little fish growing, growing, growing and then, if you catch that fish, all that metal that was accumulated in the fish is transferred to the organism*."

The gesture shown in Figure 4 is iconic, which represents concrete objects or actions (McNeill, 2005), and is configured by the hands, in the shape of a "c," facing each other, moving away, simultaneously with the speech "*the little fish* [is] *growing, growing, growing*." According to Pozzer-Ardenghi and Roth (2005), the gesture can also be classified as an addition since it portrays a phenomenon that is not visibly available in the inscription but is associated with the theme of discourse and image. According to Lira and Stieff (2018), gestures and speech make up a single system during the externalization of an idea, in which the first carries the linguistic component and the second, the visual component. In this way, the association between inscription, speech, and gesture adds to the inscription a virtual image of a fish growing and accumulating substances, allowing the inscription's meaning to expand and for it to be associated with the discourse and text before its appearance on the OP. Used in this way, the inscription has a complementary function (Pozzer & Roth, 2003), helping the group to adequately explain the phenomenon.

Another example of the ability of students to select and communicate inscriptions during the OP includes the presentation of sampling points on maps, which was observed in all OPs analyzed. Figure 5 illustrates the OP-G2 slide with the map of sampling points chosen by the characters of the case study.

In Figure 5, the map provided to G2 during the case resolution activities is presented on the slide with the title "Demarcation of Sampling Points." A map has the ability to represent the most striking elements of the space portrayed, and it is used to identify, locate, and understand the distribution of different phenomena (Fonseca, 2010). In the case of OP-G2, the map illustrates and helps present the location of the sediment collection points marked in the region by the case study characters. This is evidence of inscription selection skills.

Another version of this map had already been introduced in the OP-G2 when the presenter instructed the audience about the meanings of the various graphical elements on the map (stars, pentagons, etc.). Thus, the presentation of the map in Figure 5 takes place through a multimodal communicative strategy that highlights the graphical elements not previously referred to in the OP, that is, the sampling points. For example, Point 2 on the map is highlighted in the OP-G2 presenter's statement, "*Point 2 is where there is the greatest interference from agriculture and livestock (…) you can see that it is well surrounded by everything* [points to stars on the map]." As the presenter had already instructed the audience that the stars on the map symbolize agricultural activity, simply pointing to the stars on the map during the presentation of the slide in Figure 5 promotes the understanding that Point 2 was impacted by these activities, which also justifies the choice of Point 2 as a sampling point. A similar situation is identified in the discussion of the other points, giving the map a complementary function. This is evidence of the sophisticated nature of G2 members' graphical literacy skills, as they coherently coordinated a series of similar inscriptions throughout the OP-G2 to reason and develop their solution for the case study. This strategic use of a set of comparable inscriptions was also observed in OP-G1 and OP-G3, evident in their use of a set of maps, tables, and graphs.

Another example that provides evidence of the skills of selecting and communicating with inscriptions is illustrated in Figure 6, with the use of maps positioned side by side on the slide,

FIGURE 4 Gestures performed synchronously with the word "growing" during oral presentation-G3.

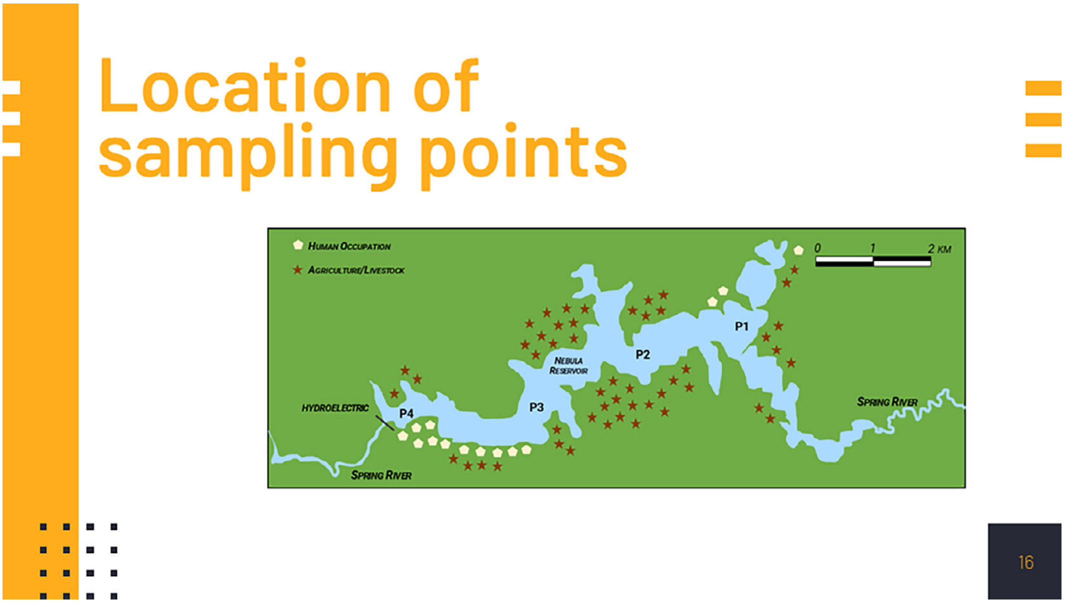


FIGURE 5 Oral presentation-G2 Slide with a map showing the sampling points chosen by the characters.

which is observed in OP-G1 and OP-G3. Figure 6 illustrates the use of similar maps arranged in parallel to compare the sampling points chosen by the students in G1 and the characters of the case study, but this same strategy has been used in the OP-G3 to discuss the data resulted from the analysis of material collected in the sampling points.

The slide shown in Figure 6 has no title and follows the presentation of the map with the sampling points chosen by the characters in the case study. In it, it is possible to visualize two maps and blue arrows between them, which indicate that the map on the left presents the points chosen by the students in G1, and the map on the right, the points chosen by the characters of the case study. Below the maps, bullet points present text that highlights the similarities between students' and the characters' choice of sampling points. The insertion of two inscriptions of the same nature side by side allows for external comparisons to be made between them, which highlights similarities and differences between the visually similar images. Thus, the maps allow and help the group to compare the demarcations of the sampling points.

However, the side-by-side positioning of two inscriptions is not enough to give meaning to them. Rather, it is necessary to instruct the audience on how to look for differences and similarities between inscriptions. Given that one of the maps had already been introduced before, the students in G1 devised a communicative strategy similar to the one on the slide in Figure 5, in which prior information and different modes of communication are used to highlight new graphical elements of the inscription (sampling points chosen by the students). On the slide in Figure 6, this strategy is used to compare demarcation points of the students and of the original characters in the case study.

The multimodal discourse of the OP-G1 presenter, "*We took some similar points in parts (...) that would be next to the lead mines* [points to Point 6 on the map on the left], *to analyze whether they really bring any importance in this river, in its contamination*" highlights and justifies the choice of Point 6 by the students in G1. Given that the OP-G1 presenter already stated that the stars represent the lead mines, the association of the inscription with speech and gestures

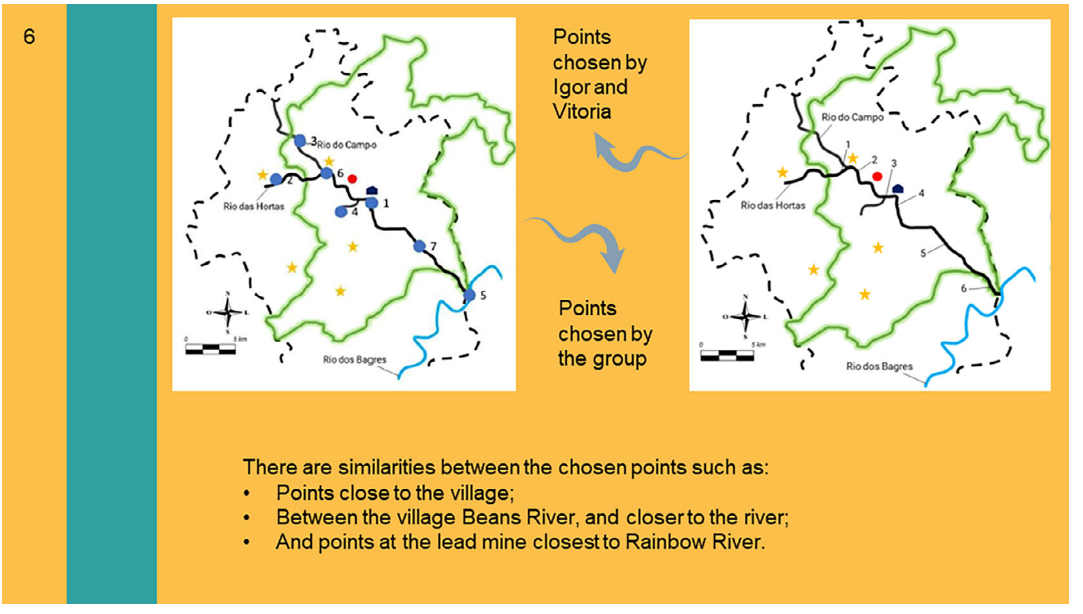


FIGURE 6 Oral presentation-G1 slide showing maps with sampling points chosen by the group (on the left) and the characters of the case study (on the right), positioned side by side for comparison.

identifies and characterizes Point 6 as the one closer to the lead mine, even if the presenter did not use the term "Point 6." The gestures used are of the highlighting-deictic type, of a circular shape, and draw attention to an area of the inscription where something must be found (Pozzer-Ardenghi & Roth, 2005). The gestures, in association with the side-by-side positioning of the maps, allow the audience to compare the same area on the characters' map (on the right) previously referred to in relation to the G1's map (on the left) and find a sampling point there too. Finally, the section "*to analyze whether they really have any importance in this river, in its contamination*," in addition to expanding the meaning of the map, connects the inscriptions with the textual elements of the slide and further explains the comparison between the maps. Similar communication occurs for the other points chosen by this group of students, and the maps, therefore, have a complementary function.

The gestures are performed predominantly on G1's map (on the left). The characters' map is pointed out only once, when the OP-G1 presenter announces that G1 members have marked an extra point in relation to those marked by the characters of the case study. In this sense, gestures, speech, and inscriptions positioned side by side work together to compare the two maps, highlighting what is different between a new inscription and an inscription that has just been explained and can be revisited on the same slide. The different communicative strategies in the comparison of the maps provide evidence of the skill of inscription communication during the OP.

5.3 | Claim 3: Students' graphical literacy is demonstrated in their skill to produce inscriptions for OPs

The creation of inscriptions is not a neutral act but one that is embedded in cultural norms; therefore, for OPs, it must consider the context and the conceptual understanding that one wishes to foster in the audience. The production of inscriptions can occur in two main ways: *translation* and *transposition*. *Translation* is the process of converting information from written or numerical texts into different types of inscriptions or from one type of inscription to another (e.g., from a table to a graph). *Transposition*, on the other hand, refers to moving information between inscriptions of the same type (e.g., from one table to another) (Roth et al., 2005). Properly constructed inscriptions organize information and facilitate the recognition of patterns that might otherwise remain obscured within the complexities of raw data (Fan, 2015). From the Interaction Analysis, our third claim is that students demonstrate graphical literacy through their skill of producing inscriptions for OPs. This was evident in our data when students:

- Produced and used inscriptions to present the case study narrative;
- Produced and used flowcharts to describe and explain experimental procedures performed to solve the case study;
- Produced and used tables to compare experimental procedures and discuss data for solving the case study;
- Produced and used graphics to discuss data to resolve the case study; and
- Produced and associated inscriptions of different natures to discuss data in the resolution of the case study.

G3 used inscriptions during the case study narrative of their OP, which were distributed in a series of slides, as illustrated in Figure 7.

The two slides in Figure 7 highlight aspects of the story of the case study G3 solved. The inscriptions G3 students produced are iconic drawings and their use relates to the qualitative nature of the information presented. That is, their insertion makes it possible to create iconic references for the characters of the case study. The inscriptions are co-thematic with the slide written elements, and a label inserted underneath the image names the characters. The iconic designs inserted on these slides were created by G3 members in the Bitmoji application for creating personalized avatars. In the sense that the elaboration of graphic arts of characters and scenarios for storytelling can be a task that demands a lot of time and effort, the use of the application is reported in the literature as a simple, fast, and effective strategy to facilitate the process of story illustration and communication (Costa Junior et al., 2022). The case narrative did not provide details about the physical traits of the characters; thus, the avatars add visual

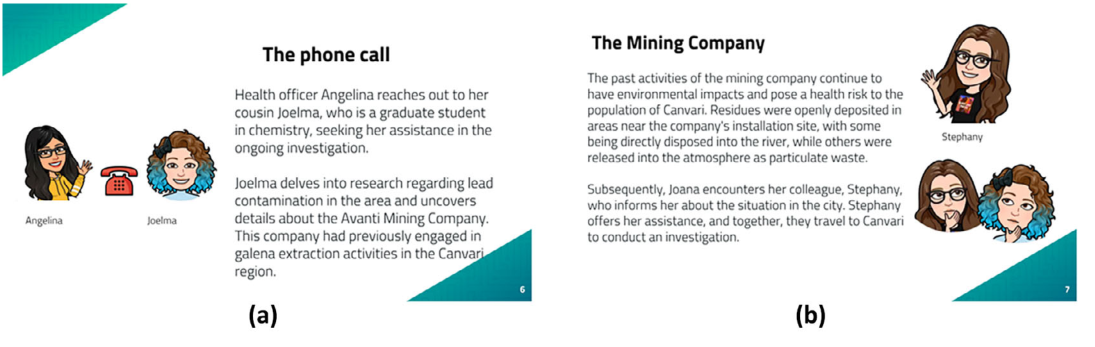


FIGURE 7 Iconic drawings produced by students to enrich the narrative of the case in oral presentation-G3 slides. (a) Slide 6. (b) Slide 7.

information regarding the case study characters, enriching the narrative. During the OP-G3, the inscriptions on slide 6 (Figure 7a) are cited and pointed out by the OP-G3 presenter, stating, "*Here, we have Angelina and Joelma*" with prominent deictic gestures. This verbal and gestural referencing of the inscriptions classifies them as illustrative.

During the resolution of the case studies, information about the experimental sample preparation procedures chosen by the characters was presented to the groups. In OP-G1 and OP-G2, the production of flowcharts provided evidence of graphical literacy to the extent that the students summarized written information provided to them in the form of a structured inscription. Figure 8 illustrates G2's use of a flowchart to present sample preparation.

Flowcharts are inscriptions that portray qualitative information about the sequence of steps, chronologically, in a process. The slide in Figure 8 is entitled "Sample Preparation." It contains a flowchart without a caption, consisting of colored text boxes, which portray the stages of the sample preparation process, and connection lines, which represent the transitions between stages. Therefore, in this example, inscription production is observed by the visual schematization of a written text and the *translation* of the written mode of communication into imagery. Ainsworth et al. (2007) point out that, in the context of producing an inscription to be presented to colleagues, adding written text characterizes a strategy used by students to make it more understandable. Comparing the information provided in the narrative with that provided in the flowchart, it is also evident the group engaged in synthesis of the content, as the sample preparation process is presented without detailing, for example, the volumes and concentration of added substances, highlighting only the sequential steps of the process.

Even though the inscription did not include other details about the process, the OP-G2 presenter used speech to add the information missing from the inscription. For example, after highlighting the first addition of nitric acid in the preparation of pseudo-total samples, the OP-G2 presenter stated that the sample was left "*at reflux for about 15 min*," a step with no visual correspondence in the flowchart. This selection of what to include in the inscription

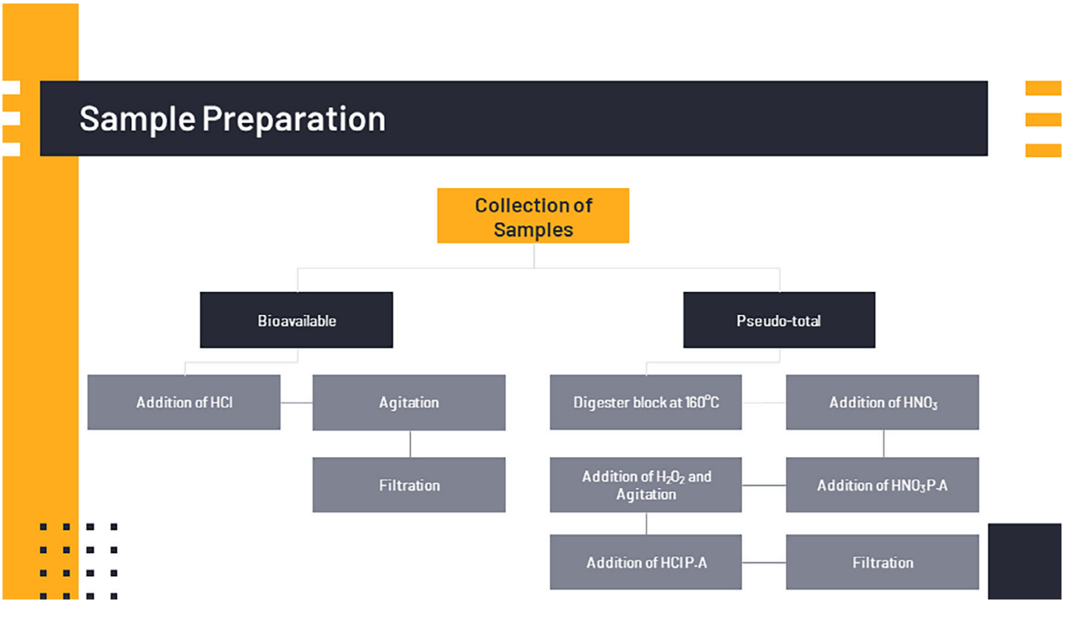


FIGURE 8 Oral presentation-G2 slide with a sample preparation flowchart the group produced.

demonstrates selection and communication skills associated to the ability to produce the inscription, and all three skills are intertwined to showcase the students' graphical literacy.

Tables were used in all OPs for different purposes. In OP-G3, a table was used to compare the analytical technique proposed by the group with that proposed by the characters in the case study, as shown in Figure 9.

The slide has the title "Comparison of equipment," and the OP-G3 presenter stated, "*In this table, I showed some differences very briefly*," clearly identifying the table as the means selected to present this comparison. The table presents three categories on the leftmost column (cost, magnitude, and limits of detection), with face emojis representing the students' assessment of the two choices of equipment: ICP-MS, on the left, and ICP atomic emission spectroscopy, on the right. In the central column of the table, the two happy faces indicate the group's approval of this choice of equipment regarding magnitude and limits of detection, but an unhappy face in relation to costs. The OP-G3 presenter justified the G3 members' choice of equipment in the following statement: "*because, despite the high cost, the equipment is very precise and, therefore, the result of the research is more efficient*." In this sense, the production of the table is an example of *translation* from the verbal to the imagery mode of communication.

The production of tables in chemistry teaching is highly associated with the execution of experimental activities and the organization of knowledge. In this case, the production of the table represents an attempt to visually display information from a written text, combining symbolic and textual elements that allow, in a satisfactory way, to compare the equipment proposed for the experiments and the students' assessment of this equipment, which ultimately justifies their choice.

Additionally, the insertion of emojis, defined as pictograms of faces, objects, animals, symbols, and many others, is an interesting choice for this inscription. Emojis are part of everyday life and are used extensively by those who have access to the internet, social networks, and digital media, which ends up socially conventionalizing meanings and situations in which they are

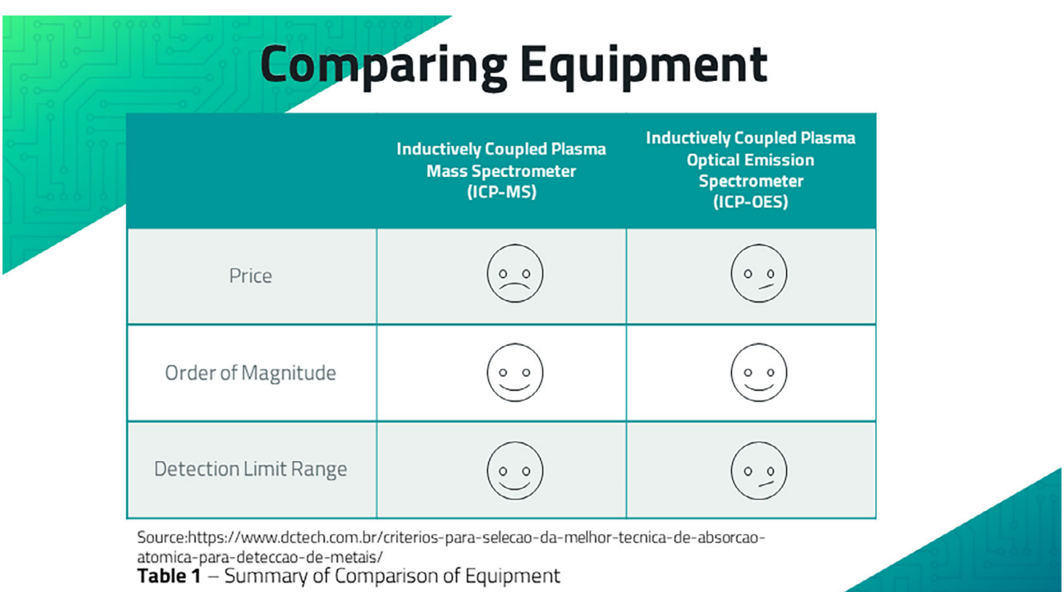


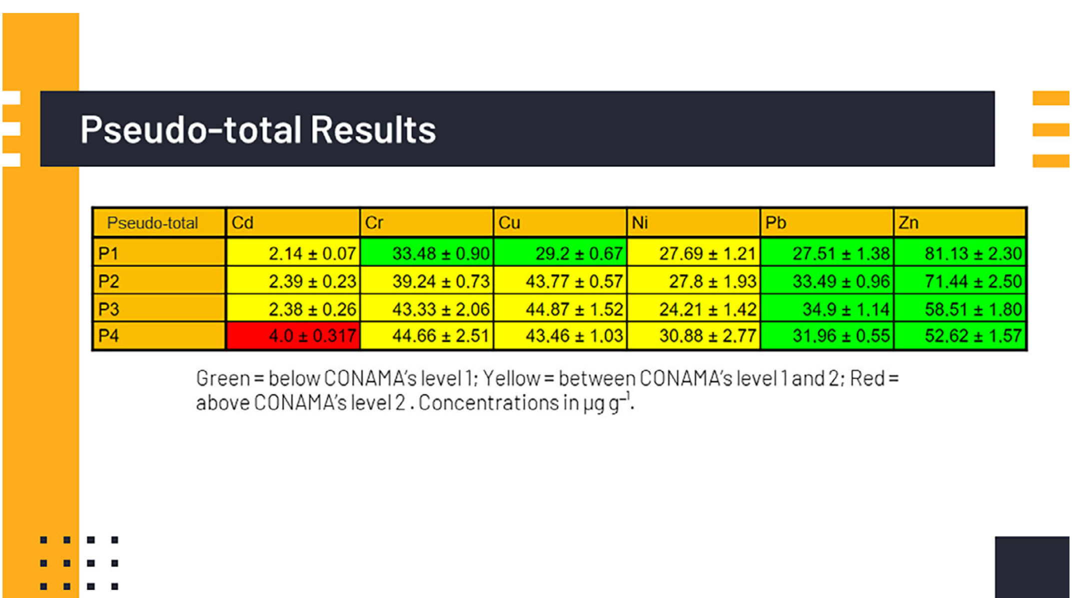
FIGURE 9 EO-G3 slide with a table.

used (Albert, 2020). Thus, their inclusion in the table in Figure 9 reflects aspects reported by Kędra and Žakevičiūtė (2019) concerning the communicative practices of current students being mediated by visual representations widely shared on social media and the internet, which represents the influence of digital culture in expanding the multimodality of scientific language and may also represent a strategy to bring it closer to everyday language and make it more attractive (Costa & Albuquerque, 2021; Paiva, 2016).

In Western culture, tables are generally read from top to bottom, from left to right, which determines the order of presenting the comparison parameters of the techniques and the emojis in the table. Thus, the first parameter of comparison highlighted in the OP-G3 is the cost. To draw attention and name the emojis, the OP-G3 presenter associates the use of prominent deictic gestures to the statement "*the cost, here* [points to the sad face emoji in the central column of the table, first row under the table heading], *we have a sad face because it is very expensive, and this one* [points to emoji for confused face on the rightmost column], *(…) because it is very expensive too, but not as expensive as ICP*." The use of emojis in the table is a quick and effective way to compare equipment and justify their choice of equipment in relation to the assessment criteria G3 members used.

In the OP-G1 and OP-G2, a different type of table was used to discuss metal concentration data in the sediments. Figure 10 illustrates the use in OP-G2 of a table to assess the contamination of the sediments by heavy metals.

The slide shown in Figure 10 is titled *Pseudo-total Results*. The table presented color-coded cells and a footnote explaining what the colors represent. Tables are inscriptions that generally portray quantitative information. In this case, the information on the table provides subsidies for the quantitative discussion of the data and resolution of the case study regarding evaluating the metal concentrations in the sediments and contamination of the water resource. G2 members produced this inscription as an alternative visual representation to one of the tables provided in the case study, illustrated in Figure 11.



Pseudo-total	Cd	Cr	Cu	Ni	Pb	Zn
P1	2.14 ± 0.07	33.48 ± 0.90	29.2 ± 0.67	27.69 ± 1.21	27.51 ± 1.38	81.13 ± 2.30
P2	2.39 ± 0.23	39.24 ± 0.73	43.77 ± 0.57	27.8 ± 1.93	33.49 ± 0.96	71.44 ± 2.50
P3	2.38 ± 0.26	43.33 ± 2.06	44.87 ± 1.52	24.21 ± 1.42	34.9 ± 1.14	58.51 ± 1.80
P4	4.0 ± 0.317	44.66 ± 2.51	43.46 ± 1.03	30.88 ± 2.77	31.96 ± 0.55	52.62 ± 1.57

FIGURE 10 Table created by G2, included in one of the slides in oral presentation-G2.

The original table provided to students presents data on the concentration of aluminum, cadmium, lead, cobalt, copper, chromium, iron, manganese, nickel, silver, and zinc in the sediments. It is taken as the basis for the construction of the table in Figure 10, with notable exclusions and additions of information. G2 members used maximum concentration values recommended by the *Conselho Nacional do Meio Ambiente*—CONAMA (National Council for the Environment) to evaluate the data in the resolution of the case study. Since that legislation does not present values for aluminum, cobalt, iron, manganese, and silver, data for these metals were excluded from the table G2 members produced. Also excluded were captions, footnotes, and general mean concentration values of metals.

The addition of colors to the cells to indicate concentration levels exceeding the values recommended by CONAMA follows socially conventionalized patterns, in which red and green generally acquire opposite meanings. This dichotomy comes from the presence of traffic lights in cities, with the first color being understood as "stop, danger, and prohibition" and the second as "go, permission, and safety" and yellow understood as "yield, attention, and caution" (Castro & Pereira, 2018; Pastoureau, 1993). Moreover, selected information on the first row of the table in Figure 11 was transferred to the footnote of the table produced by the students, in Figure 10, indicating what the amounts represent in this table (concentration in μg/g). These modifications of the original table and the selection of what and how to present information are evidence of the students' graphical literacy, in terms of selection and production. The addition of colors and the exclusion of information that did not apply to the case allowed G2 members to create a streamlined table that highlights pertinent information. In this case, production represents a process of *transposition* between inscriptions of the same type.

The feature of the table produced by G2 members directly impacted the speech and the communicative strategies using the OP-G2 when discoursing about this slide (Figure 10), evidencing the development of inscription communication skills in OPs. The OP-G2 presenter provided instructions to the audience about the meaning of each color on the table: "*The yellow points* [points to the footnote of the table], *those above level one and below level two (…) they have the lowest probability and lowest risk of causing a problem in human health and the biota of the dam*." The multimodal discourse is also used in the OP-G2 discussion of the concentrations of each metal, explaining and justifying patterns and behaviors based on information from the literature, such as, for example, "*copper, we can see that, from Point 2* [points to value of copper on Point 2] *it rises a lot and then remains constant* [gesture for sketching the values of the copper column], *and as it is used for some fertilizers in wheat fields, it can contaminate the water, and, thus, going to the dam*." The addition of information in this quote exemplifies the expansion of the meaning of the information provided on the table. The discussion and presentation of the data are guided by the colors of the table, giving it an expository function.

Table 1. Concentration of pseudo total metals in sediments from the Nebula Reservoir at the four collection points.

Sampling Points	Concentration (μg/g)										
	Ag	Al*	Cd	Co	Cr	Cu	Fe*	Mn	Ni	Pb	Zn
P1	4.08 ± 0.32	76.39 ± 2.06	2.14 ± 0.07	27.03 ± 1.53	33.48 ± 0.90	29.20 ± 0.67	44.57 ± 2.31	340.85 ± 9.99	27.69 ± 1.21	27.51 ± 1.38	81.13 ± 2.30
P2	4.55 ± 0.11	72.11 ± 6.52	2.39 ± 0.23	27.34 ± 0.70	39.24 ± 0.73	43.77 ± 0.57	43.59 ± 3.75	277.95 ± 3.38	27.80 ± 1.93	33.49 ± 0.96	71.44 ± 2.50
P3	5.66 ± 0.16	79.01 ± 1.66	2.38 ± 0.26	28.21 ± 0.93	43.33 ± 2.06	44.87 ± 1.52	62.05 ± 6.65	318.50 ± 0.38	24.21 ± 1.42	34.90 ± 1.14	58.51 ± 1.80
P4	5.17 ± 0.32	74.23 ± 2.08	4.07 ± 0.31	29.43 ± 0.69	44.66 ± 2.51	43.46 ± 1.03	62.09 ± 1.90	408.27 ± 7.81	30.88 ± 2.77	31.96 ± 0.55	52.62 ± 1.57
Overall Average	4.86 ± 0.69	75.44 ± 2.96	2.74 ± 0.89	28.00 ± 1.07	40.18 ± 5.02	40.32 ± 7.44	53.08 ± 1.04	336.39 ± 54.53	27.65 ± 2.72	31.96 ± 3.20	65.93 ± 12.82

(*) Results expressed in mg/g, other sediment results expressed in μg/g.

FIGURE 11 Table provided in the case study *Toxi-Cd Fishes in Dam*.

The groups also produced graphs as part of the case study resolution. G1 presented their graph during the OP, as illustrated in Figure 12.

On the slide illustrated in Figure 12, the title "Graphics" and the bar graph, as well as a iconic drawing are present. The iconic drawings at the bottom right of the slide have a decorative function, aligning to the theme of the presentation but not being referred to by the group. These drawings, as mentioned earlier in this paper, were part of the slide template G1 members included in their OP. Of interest in this case is the graph G1 members produced. Graphs are inscriptions used rhetorically in scientific discourse to support arguments and present quantitative information and numerical relationships of the phenomenon under study (Roth et al., 2005; Roth & Bowen, 2000). In previous slides, the OP-G1 presenter showed tables highlighting and evaluating the metal concentrations compared to standard reference values. In this sense, the graph in Figure 12 reinforces and emphasizes the considerations made during the discussion on and about the tables.

The OP-G1 presenter's statement "*We created this graph to show the difference. And we made an average between points with similar location*" reflects the intentionality and details of the creation of the inscription. Wu and Krajcik (2006) underscore the importance of purposefully producing and selecting inscriptions to support specific arguments, which is crucial for students' engagement in meaningful scientific practices encouraging them to consider how inscriptions can serve specific reasoning purposes. The production of the graph in Figure 12 is an example of *translation* from one type of inscription (table) to another (graph), with students engaging in mathematical and scientific practices. The calculation of the average concentration for certain sampling points represents the reduction and collapse of information in an attempt to make salient phenomena of interest, which, according to Roth et al. (2005), is a rhetorical strategy used in convincing arguments. The averages are arranged on the ordinate (y-axis), and the sampling points are on the abscissa (x-axis) of the graph. Note the inclusion of structural elements, such as labels, captions, and units of measurement, which, according to García García (2005),

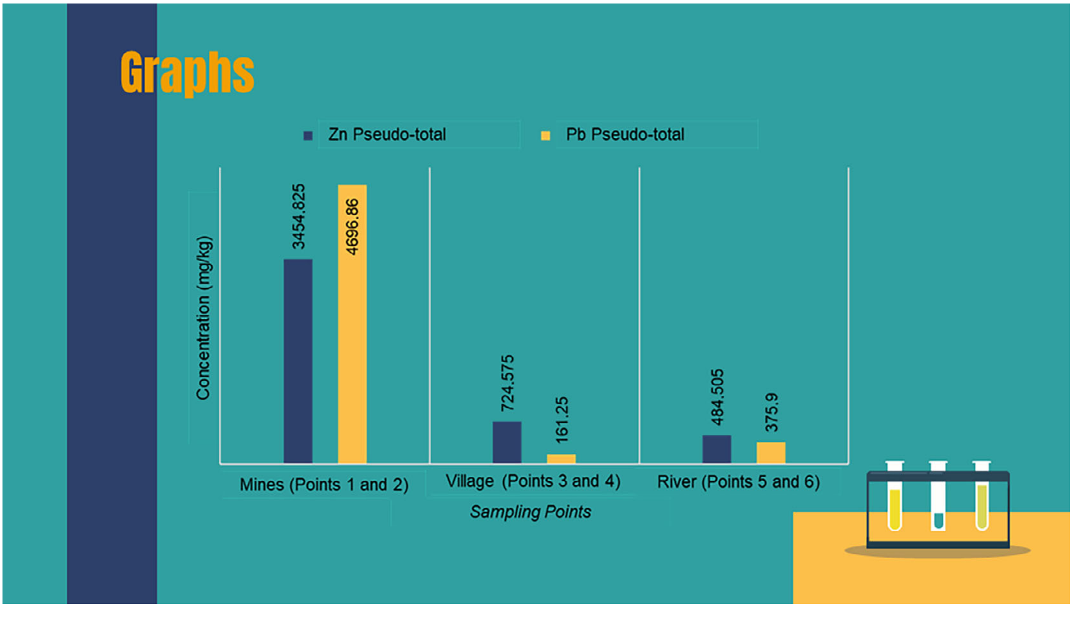


FIGURE 12 Bar graph produced by G1 presented on a slide during their oral presentation.

help establish relations between qualitative and quantitative information and in the realization of abstract graphic manipulation.

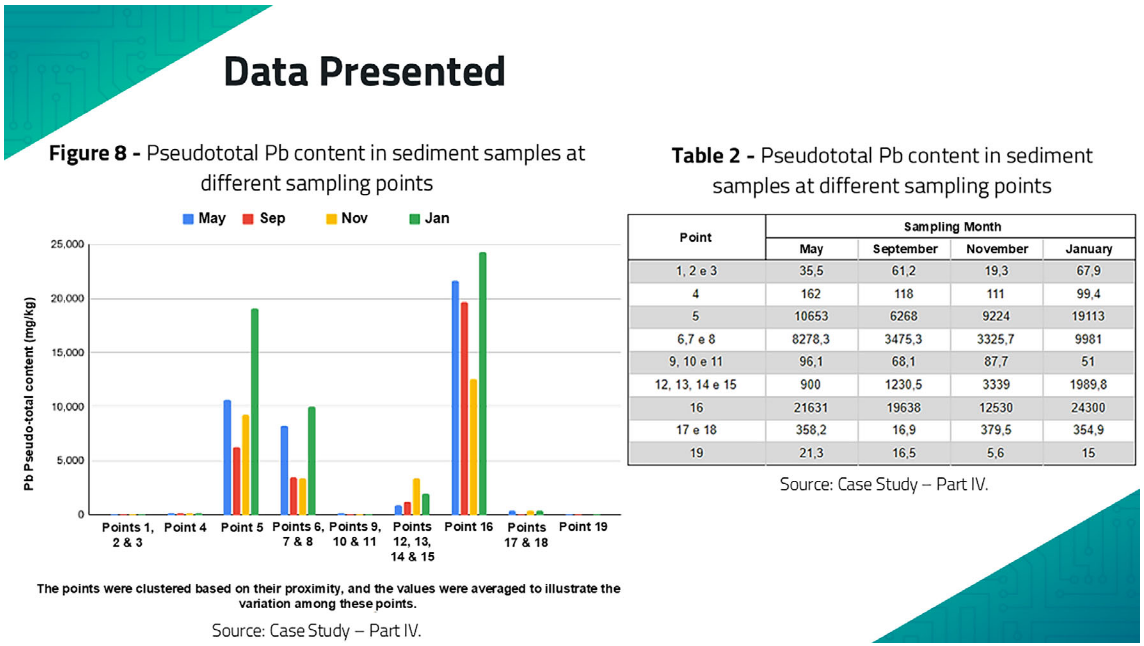
While explaining the graph on the slide in Figure 12, the OP-G1 presenter mentioned the purpose and details of the production of the inscription and instructed the audience about the features of the graph that must be perceived to adequately interpret the information on it. The speaker also made comparisons and drew conclusions about the data presented on the graph (e.g., "*lead values are above the permissible levels, (...) and so is zinc, in the points close to the mine (...) it is considerable that these points would be the most contaminated*"), which gives the inscription an expository function and achieves the purpose of its production, that is, to identify the primary location of the contamination.

In all the OPs analyzed, the groups used the association of inscriptions of different types for articulating and discussing data while elaborating conclusions to the cases. Figure 13 exemplifies the association of graphs and tables by G3.

On the slide in Figure 13, titled "Data Presented," we can see a graph and a table, each with a title. Tables and graphs are inscriptions used to illustrate a phenomenon or entity through its numerical and mathematical relationships, being widely used in science, as they allow quick and unobstructed identification of patterns and correlations. Both inscriptions on the slide originated from the data tables provided during the case study resolution activities. In this way, the graph is produced from a *translation* between different types of inscriptions and the table from the *transposition* of inscriptions of the same type. As the footnote that accompanies the graph indicates, the production of the numerical data for the graph also involved mathematical practices since the arithmetic mean was calculated for particular sets of points of interest by G3 members: "*We grouped points due to their proximity, because we wanted to do investigation in these specific areas, to know which area has the highest focus of contamination, that's why we brought together some points*." That is, G3 members produced and selected the inscriptions to synthesize the data and facilitate the identification of contaminated areas.

The case study solved by G3 stands out for its extensive dataset, providing students with a significant amount of information to analyze. It is evident that G3 members invested effort and deliberated on the most effective ways to present this wealth of data, to bring to light the areas contaminated. The production of the inscription initially involved selecting data referring to the pseudo-total fraction, agglutination of the sampling points of interest and calculation of the arithmetic mean of the concentration in these points. The group arranged the averages by month of the year in the columns of the table and the clustered sets of sampling points in the rows. The caption of the original table was also reworked. For the production of the graph, the averages were arranged on the ordinate and the sets of points on the abscissa. The graph includes several structural elements that García García (2005) recommended, such as labels, captions, measurement units, and titles.

The use of the graph and the table side by side on the slide in Figure 13 is attributed to the fact that, while the contaminated areas may be readily discernible in the graph, the concentration values are not clearly visible to the audience. Hence, the table serves to facilitate easy reference to these values, enhanced by the side-by-side position with the graph. This illustrates the G3 members' strategic use of inscriptions for distinct yet complementary purposes. For example, the OP-G3 presenter's statement, "*Here* [points to the graph] *we don't know the values, but if we take a look at the table, for example, Point 16, in January* [points to the graph] *we come to 16* [pointing to the table] *and we find 24,300 mg/kg*" provides evidence of the G3 members' graphical literacy skills, as they recognize that generating an effective scientific communication and



Point	Sampling Month			
	May	September	November	January
1, 2 e 3	35,5	61,2	19,3	67,9
4	162	118	111	99,4
5	10653	6268	9224	19113
6,7 e 8	8278,3	3475,3	3325,7	9981
9, 10 e 11	96,1	68,1	87,7	51
12, 13, 14 e 15	900	1230,5	3339	1989,8
16	21631	19638	12530	24300
17 e 18	358,2	16,9	379,5	354,9
19	21,3	16,5	5,6	15

FIGURE 13 The association of a table and a graph during oral presentation-G3.

argument involves coordinating a cascade of inscriptions, each providing a complementary perspective.

During the OP-G3, the presenter instructed the audience on how to use the graph in association with the table (e.g., "*how do I read this?*"). Providing these instructions highlights essential elements for coordinating the interpretation of the data since, according to Roth et al. (2005), these can be used as markers. Indeed, the sets of sampling points on the abscissa of the graph and the different colors of the bars were highlighted through speech in association with deictic gestures. Likewise, the use of deictic gestures guided the interpretation of the values in the table. In line with using the inscriptions to verify which areas are most contaminated, the OP-G3 presenter highlighted the values of Point 16, which was the most contaminated, to instruct the audience on how to associate the information on the graph and table. In this instance, the inscriptions have a complementary function, helping the G3 members discuss the data and resolve the problem, and the production and communication of these inscriptions during the OP-G3 are further evidence of the students' graphical literacy.

5.4 | Limitations

Although students worked collaboratively to design their OP, our analysis focused on the individual student presenting the OP; thus, even though we consider the selection and production of inscriptions as a collaborative work among students within the same group, only the presenter of the OP demonstrated the skill of communicating with inscriptions, which is a limitation of the context of the data collection methods used in this study.

6 | CONCLUSIONS AND RECOMMENDATIONS

This study reported results from the analysis of multimodal OPs designed and presented by first-year undergraduate chemistry students, with the aim of discerning evidence of their graphical literacy. Employing Interaction Analysis, we generated claims, substantiated by examples illustrating situations where students' skills of selection, production, and communication with inscriptions make evident their graphical literacy.

The value of these claims lies in their potential to offer educators clear directives for assessing graphical literacy and the effective use of inscriptions in OPs. By focusing on the skills of selecting, producing, and communicating with inscriptions and how these became evident during the OPs, educators are better equipped to evaluate the inscription practices in their classes, enabling a more targeted and informed assessment of students' graphical literacy and communicative effectiveness. For instance, educators are encouraged to observe whether students are employing templates with inscriptions that enhance the rhetorical effectiveness of their presentations, whether they have appropriately selected or produced inscriptions to convey pertinent quantitative/qualitative relationships, and whether they effectively communicate the meaning of these inscriptions in a manner that considers the audience, the purpose of the presentation, and its context.

Another key strength of these claims is their performative nature: these claims are not tied to specific content but are instead performative. The specific situations used to substantiate the claims can inform the development of assessment tools, such as rubrics, observation checklists, or peer-assessment frameworks for evaluating graphical literacy in OPs. Further investigations into the use of inscriptions in other multimodal scientific communication genres (e.g., posters, videos, and seminars) could yield additional situations not captured in our data. For example, Lawrie and Bartle (2013) emphasize the significance of the source of the inscription—whether it is produced by the students or sourced from online resources—as a factor that can help differentiate the levels of explanation of concepts. Moreover, due to their inherent nature, these claims can be effectively transferred and applied across various domains and educational settings that utilize OPs. This includes not only science education but also disciplines such as engineering, social sciences, and humanities, where multimodal presentations are also common.

The proactive selection, production, and communication of inscriptions in OPs in our study, representing the culmination of an investigative process, epitomize the core and shared practices involved in constructing scientific knowledge, transcending the limitations of traditional instructional approaches. Indeed, the outcomes of this study are intimately tied to the distinctive educational context in which it unfolded. The interrupted case study method immersed students in a learning experience meticulously crafted to provide an authentic initiation into scientific inquiry, offering opportunities for students to maintain a sense of autonomy while navigating the complexities of inscriptions creation, use and interpretation, and to cultivate and demonstrate their graphical literacy. Alongside explicit instructions on inscription usage, this approach fosters students' understanding of the role of inscriptions in scientific knowledge development and their perception of inscriptions as visual aids and communicative tools for facilitating coherent and effective communication.

Students' graphical literacy can be developed and made evident through the selection of inscriptions for scientific communication. In designing OP for communicating scientific findings, such as the resolution of case studies, students are required to critically assess and decide whether inscriptions possess the requisite visual features and supplementary resources to effectively convey diverse types of information in an unambiguously and appropriately manner, tailored to the specific purpose and audience. These considerations serve to stimulate decision-making and foster students to develop and refine their graphical literacy skills, enabling them to address functional aspects of inscriptions and ensure conciseness and appropriateness in their OPs. For instance, in this study, when aiming to provide examples and visually portray qualitative aspects of scientific entities and phenomena, students adeptly opted for photographs and drawings. In the context of discussion of quantitative data, the selection of tables and graphs was pertinent. Furthermore, comparing maps to illustrate and justify sampling location choices, and utilizing flowcharts to elucidate procedural steps of experiments were also observed, all of which indicate graphical literacy through appropriate inscription selection, communication, and production.

Moreover, graphical literacy can be developed and made evident when students use inscriptions rhetorically. The students in our study were provided instructions pertaining to the appropriate use of inscriptions for scientific communication, but, instead of being constrained by predefined protocols, inscriptions, and resolutions, students were afforded the autonomy to determine how they wished to employ inscriptions within their OP. Instances where students selected templates featuring inscriptions relevant to chemistry laboratory settings to establish a thematic context and capture the audience's attention; the placement of adjacent maps depicting sampling points on a single slide, facilitating seamless comparative analysis of these points; and the association of graphs and tables to draw conclusions from numerical data presented in these two types of inscriptions demonstrate students comprehension and utilization of inscriptions' rhetorical power during their OP.

Students' graphical literacy can also be developed and made evident through communicating with inscriptions, connecting them with an array of other multimodal resources, such as speech, textual attributes of the slides (titles, captions, texts, etc.), deictic and iconic gestures, animations, etc. In this study, the association of these elements served to facilitate effective communication and to provide convincing arguments for the students' solutions of the case studies. Within this framework, being graphically literate hinges upon the adept orchestration of multimodal resources to present, discuss, explain, and compare concepts, procedures, and data.

A recurring communicative occurrence within the OPs analyzed here pertains to the integration of inscriptions with speech and deictic gestures, aiming to describe the inscription visual elements and attributes. It was common to observe OP presenters identifying the axes and units of measurement featured in graphs, the meaning of colors used in tables, symbols on maps, among other aspects. Hence, the competence to effectively communicate with inscriptions by graphically literate individuals is intricately tied to the understanding that the mere inclusion of inscriptions within presentations does not alone suffice to provide substantiating evidence for claims and that diverse audiences perceive inscriptions differently. This underscores the significance of describing and explaining how to read the inscriptions.

Instead of solely emphasizing formal aspects of the scientific method, students can enhance their graphical literacy by actively engaging in the scientific generation of knowledge in classrooms. This involves producing, coordinating, and transforming inscriptions to effectively communicate scientific concepts and findings. The activities involved in inscription production in our study are complex and multifaceted, encompassing various dimensions, such as the use of information and communication technologies, the use of conventionalized symbols, the inclusion of textual and structural elements, the engagement in common mathematical practices and in practices authentic to scientific knowledge production. In this study, the students' immersion in these activities facilitated the creation of cascades of inscriptions to illustrate the characters of the case studies, to explain and compare experimental procedures, and to discuss data for the case resolution. Graphical literacy concerning inscription production is intertwined with the acknowledgment of the necessity for utilizing relevant inscriptions to facilitate and improve the communication of data, results, arguments, and conclusions. Furthermore, the students' engagement in common shared scientific practices during inscription creation signifies their involvement in data analysis and interpretation to reinforce their grasp of the subject matter.

The identification of crucial components pertaining to students' graphical literacy can provide valuable guidance for educators in crafting effective teaching activities targeted at fostering several skills related to the use (interpretation, production, selection, and communication) of inscriptions and at enhancing students' overall scientific communication skills.

ACKNOWLEDGMENTS

This study received funding from the São Paulo Research Foundation (FAPESP—Grants 2018/23809-3 and 2020/14789-9) and the Brazilian National Council for Scientific and Technological Development (CNPq—Grant 304974/2020-0).

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ENDNOTE

[1] This study follows the Code of Ethics of the University of São Paulo (Resolution No. 4871/01).

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How to cite this article: Silva de Lima, M., Pozzer, L., & Queiroz, S. L. (2024). Evidence of graphical literacy in students' oral presentations: An example from undergraduate chemistry education. *Journal of Research in Science Teaching*, 1–31. https://doi.org/10.1002/tea.22001