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INTEGRATING COMPUTATIONAL THINKING AND WRITING-TO-LEARN AS A METHOD FOR ORGANIC COMPOUND ANALYSIS AND STRUCTURAL ELUCIDATION

Matheus F. Flores[a], **Kerlyn K. M. Hiraga**[a] **and Antonio A. S. Curvelo**[a,*]
[a]Instituto de Química de São Carlos, Universidade de São Paulo, 13566-590 São Carlos – SP, Brasil

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This report describes how 25 second-year undergraduate chemistry students perceived and were impacted by an active learning strategy introduced in the Organic Compounds Analysis course at the São Carlos Institute of Chemistry, University of São Paulo. The intervention centered on a class activity where students developed structured protocols for interpreting organic spectroscopic data. The activity integrated principles from Computational Thinking and Writing-to-Learn, encouraging students to decompose complex problems, recognize data patterns, and articulate reasoning in written form. To evaluate the impact of this intervention, a descriptive educational study was conducted using post-activity questionnaires to collect quantitative data on students' motivation, confidence, and perceptions of the protocols' usefulness. Results showed that 15 out of 25 students felt more motivated to study in advance, and 13 reported increased confidence during exams when using the protocols. Additionally, 23 students indicated that preparing the protocols deepened their understanding of organic spectroscopy concepts and improved exam performance. Although some students reported difficulties synthesizing information from multiple spectroscopic techniques, the overall reception was positive. The findings suggest this activity not only enhanced learning efficacy in organic spectroscopy but also helped students develop greater confidence during assessments.

Keywords: second-year undergraduate; organic chemistry; hands-on learning; student confidence; spectroscopy.

INTRODUCTION

Student performance in Organic Chemistry is shaped by a complex interplay of factors, including teaching approaches, curriculum design, students' prior educational experiences, and broader issues of educational equity.[1-3] Organic Chemistry, in particular, is often perceived as highly challenging due to its abstract concepts and the cognitive demands associated with problem-solving and representational competence.[4] Additionally, affective factors such as motivation, study strategies, and anxiety also influence how students engage with the subject and perform in assessments. For some students, anxiety can serve as a motivator, encouraging deeper engagement with the material. For others, it can hinder learning and performance by disrupting cognitive processes essential for organizing and conceptualizing content.[5-7] Addressing these challenges requires not only supporting students in developing effective learning strategies but also reflecting on how Organic Chemistry is taught and assessed.

In the specific context of Analytical Organic Chemistry, these challenges can become even more pronounced. Organic Compounds Analysis courses often focus on the identification of unknown organic compounds using a combination of instrumental techniques such as mass spectrometry (MS), infrared (IR) spectroscopy, ultraviolet-visible (UV-Vis) spectroscopy, and both ^{1}H and ^{13}C nuclear magnetic resonance (NMR) spectroscopy. Mastery of these techniques requires students to integrate knowledge from earlier Organic Chemistry courses with analytical reasoning skills to interpret multiple datasets and propose plausible molecular structures. Among these techniques, NMR spectroscopy often poses the greatest challenge, partly due to the absence of a standardized, step-by-step protocol for spectral interpretation and the need for students to independently synthesize and apply concepts they may not have fully mastered from this and previous courses.[8,9]

To help students overcome these difficulties, certain educational strategies can promote more active engagement with the material and create a more supportive learning environment.[10,11] One such strategy involves introducing elements of Computational Thinking (CT), which encourages students to break down complex problems – like structural elucidation – into smaller, manageable steps for clearer analysis.[12] Another complementary approach is Writing-to-Learn (WTL), where students interact with source materials by summarizing, interpreting, and organizing information in their own words. Through this process, they deepen their understanding, build connections between new and prior knowledge, and gain greater conceptual control over the content.[13] When combined, these two strategies can play a key role in helping students develop their own systematic procedures and protocols for organic compound identification – an essential skill given the volume and complexity of data produced by each of the studied techniques.

This manuscript outlines a class activity designed to engage students in creating clear and concise procedures/protocols for each one of the instrumental techniques learned during the course. The key learning goals were to improve students' ability to organize information effectively and deepen their understanding of the assessment content through active participation. Additionally, the creation of these protocols was also expected to act as a motivational tool, inspiring students to delve into the assessment content beforehand. To add to that, their availability during evaluations aimed to foster a calmer and less stressful learning environment.

Computational Thinking

Computational Thinking is a problem-solving methodology rooted in computer science that addresses intricate issues spanning various fields. Conceptually, it can be viewed as a contemporary application of the older Cartesian method, as both emphasize systematic reasoning,

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*e-mail: aprigio@iqsc.usp.br
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decomposition, and abstraction as means to approach complex problems. It rests, depending on the author, on four fundamental steps: (*i*) abstracting irrelevant details; (*ii*) breaking down complex systems into smaller components; (*iii*) identifying patterns within problems; and (*iv*) crafting step-by-step solutions to the problem at hand.[12,14,15]

Each of these techniques serves a distinct purpose. Abstraction allows for focusing solely on essential information for the solution while discarding irrelevant details. Decomposition facilitates a deeper analysis of complex problems by breaking them down into manageable parts. Pattern recognition enables users to discern trends, regularities, and relationships within the problem or from past experiences, enhancing understanding. Lastly, developing a step-by-step solution underscores the significance of logic and systematic reasoning in problem-solving, streamlining the resolution process.

Figure 1 shows an example of how the second and third steps of this methodology can be related with ^{13}C NMR spectroscopy. The ^{13}C spectrum can be divided into four major regions: unsaturated carbon atoms near oxygen (150-200 ppm), unsaturated carbon atoms (100-150 ppm), *sp*-hybridized and saturated carbon atoms adjacent to oxygen (50-100 ppm), and saturated carbon atoms (0-50 ppm). This division helps students by allowing them to analyze each region separately, simplifying the interpretation process.

Writing-to-Learn

Writing is a powerful tool for learning, deeply connected to cognitive processes.[16] Hayes and Flower's model[17] divide the writing process into three core components: (*i*) planning, which involves generating ideas, organizing them, and setting goals; (*ii*) text production, the act of turning those ideas into written form; and (*iii*) reviewing, which focuses on evaluating and revising the text based on the writer's objectives. These components represent distinct mental activities that occur with constant interaction throughout the writing process. For example, during the traditional "planning" phase, the writer is not just generating ideas (planning) but also beginning to put them into words (text production) and reconsidering or reorganizing them (reviewing). Similarly, while drafting, the writer may simultaneously generate new ideas (planning) or review and revise the text as they go (reviewing).

The Knowledge Constitution Process Hypothesis of Galbraith[18] emphasizes the dynamic relationship between the written text and the existing knowledge of the writer. This interaction encourages the writer to continuously revisit and refine the conceptual elements needed to complete the text, promoting knowledge acquisition through the connections formed. Building on this, Klein[19] proposes two additional hypotheses: forward search and reverse search. The forward search hypothesis suggests that written text acts as a flexible framework, helping writers identify contradictions that drive learning. The reverse search hypothesis proposes that, while writing, authors define rhetorical goals that guide content creation, and later adjust these goals as new insights emerge.

Despite the singularities in these theories, they all highlight a common theme: writing fosters reflective thinking during the learning process. Through review, reorganization, and the linking of ideas, writing not only captures knowledge but also deepens understanding by prompting ongoing reflection.

Writing-to-Learn activities are instructional strategies aimed at engaging students with educational content and deepening their conceptual understanding through the process of writing.[20,21] These activities prioritize the development of content knowledge rather than focusing on improving writing skills. Research on Writing-to-Learn assignments in chemistry classes has shown that these tasks not only reveal students' understanding of the subject matter but also enhance their grasp of key concepts.[22-24]

Reasoning for combining Computational Thinking and Writing-to-Learn

While Computational Thinking and Writing-to-Learn stem from different educational traditions – problem-solving in computer science and cognitive engagement through writing, respectively – there can be benefits of integrating these approaches, especially in STEM (Science, Technology, Engineering, and Mathematics) education. CT promotes systematic reasoning and problem decomposition, while WTL fosters reflective thinking and conceptual articulation. When used together, CT can help students structure and organize complex scientific content into logical frameworks, and WTL ensures that students engage deeply with these frameworks by translating them into their own words. In the context of organic spectroscopy, where students must interpret multiple data types (e.g., UV, IR, MS, NMR), this combination supports both analytical reasoning and conceptual understanding. Compared to conventional teaching models that focus on content delivery or rote problem-solving, this dual approach encourages metacognition, reflection, and iterative knowledge construction.

In the activity described below, the writing process is aligned with phases of Computational Thinking (Table 1). For instance, the planning phase in writing corresponds with abstraction and decomposition in CT, where students can identify relevant spectral features and organize their analysis into manageable sections. The text production phase reflects pattern recognition, as students synthesize observed data trends into written interpretations. Finally, the review phase parallels the algorithmic reasoning step, where students refine their protocols to create clear, stepwise problem-solving procedures for compound elucidation.

EXPERIMENTAL

The activity was conducted in the Organic Compounds Analysis course (course code: 7500036) at the São Carlos Institute of Chemistry,

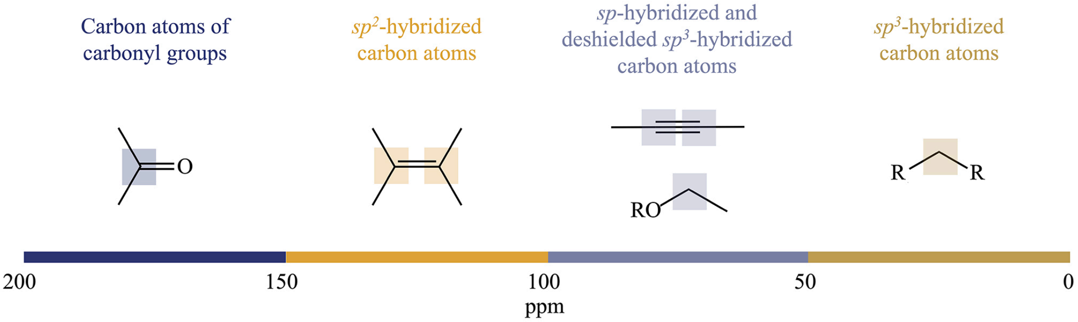


Figure 1. *Regions of the ^{13}C NMR spectrum*

Table 1. Conceptual alignment between Computational Thinking and Writing-to-Learn in the protocol development activity

Computational Thinking steps	Writing-to-Learn phases	Example from student protocols
Abstraction	planning	selecting which spectroscopic data to prioritize
Decomposition	planning	dividing the protocol into sections
Pattern recognition	text production	writing observations about spectral regions
Algorithm design	review	refining the protocol into a clear sequence for compound elucidation

University of São Paulo. This mandatory, lecture-based course is designed for second-year undergraduate chemistry students and aims to provide a solid foundation in the principles and applications of key techniques used in the systematic identification of organic compounds, including mass spectrometry, UV-Vis spectroscopy, IR spectroscopy, and both ^{1}H and ^{13}C NMR spectroscopy. There were 25 students enrolled that semester, all taking the course either for the first or second time.

As part of the activity, students were encouraged to individually create protocol documents for the structural elucidation of organic compounds, with each protocol focusing on a different spectroscopic technique covered in the course. These were developed outside of class time, based on content taught by the professor and guidance from the assistant professor.

The activity was implemented as follows.

Stage 1. Presentation and exemplification

On the first day of class, essential course information was presented, along with an introduction to the semester-long activity, emphasizing its importance for the assessments. About two weeks before each test, the assistant professor conducted a brief class session to offer suggestions and point out key information for protocols of the students. During these sessions, he also introduced the Computational Thinking thoughts, explaining how it could be applied to each technique being studied.

Figure 2 presents a scheme used to demonstrate how each idea of Computational Thinking can be applied to solve an unknown infrared (IR) spectrum with the molecular formula C_6H_7N. The first step, "abstraction", involves filtering out irrelevant details, as shown in Figure 2b, where the region below 1000 cm^{-1} is blurred. This region is part of the "fingerprint area", where spectral assignments tend to be more complex. The second step, "decomposition" – breaking down a complex system into smaller components – is shown in Figure 2c. The IR spectrum is divided into four key regions: the 4000-2500 cm^{-1} range, which corresponds to C–H, N–H, and O–H stretches; the 2500-2000 cm^{-1} range, associated with triple bonds; the 2000-1500 cm^{-1} range, corresponding to double bonds; and below 1500 cm^{-1}, which includes stretching vibrations of single bonds, except H-bonds. Once the spectrum is broken down, we can move on to "pattern recognition" (Figure 2d), where the key features of the spectrum are identified. With this information, a molecular structure can be proposed. By the end, the student can create a "step-by-step guide" to apply this methodology to other infrared spectra.

Stage 2. Preparation, submission and review

Students were allowed to prepare their protocols in the format they preferred, as long as the content fit within a single A4 page. Approximately one week before each assessment, students could submit their protocols to the assistant professor via Moodle platform for early review. Corrections and suggestions for including pertinent information were provided. On exam days, all students were allowed to bring and consult their own protocols.

Stage 3. Assessments, feedback and activity oversight

The course included three assessments:

- 1st assessment: mass spectrometry (MS).

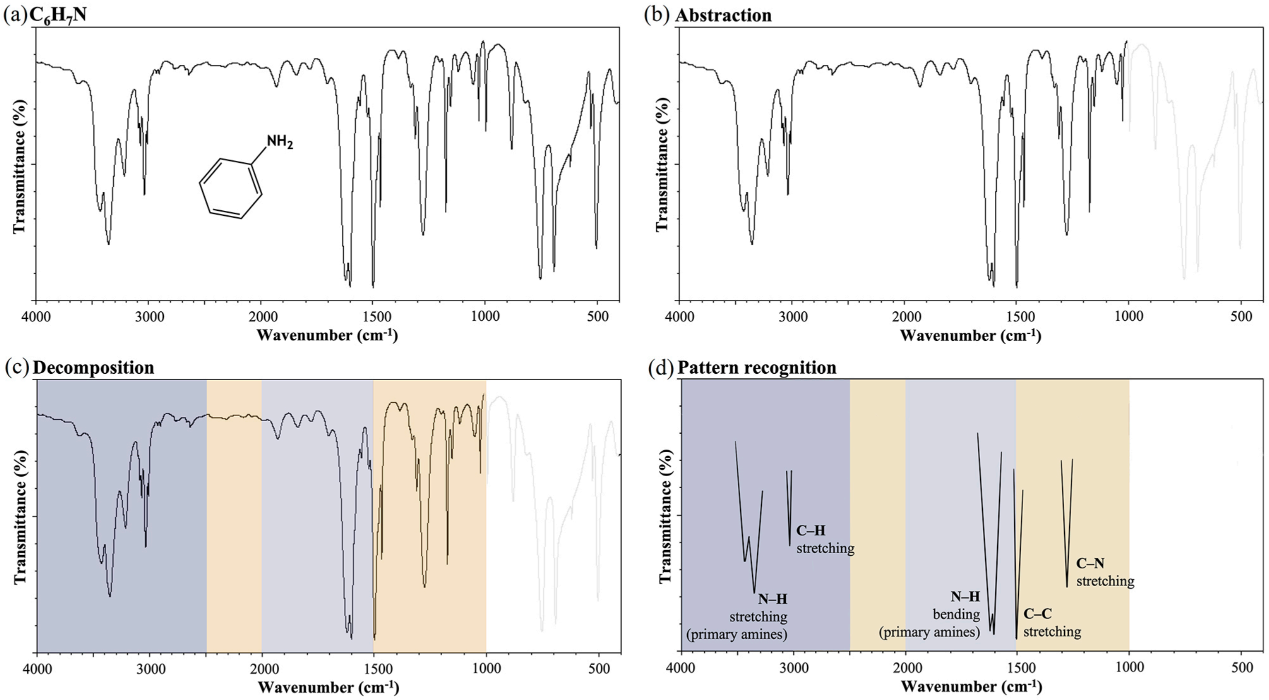


Figure 2. (a) C_6H_7N spectrum and (b-d) steps of Computational Thinking applied to solving an infrared spectrum

- 2^{nd} assessment: ultraviolet spectroscopy (UV) and infrared spectroscopy (IR).
- 3^{rd} assessment: nuclear magnetic resonance (NMR).

The assessments were composed of five open-ended questions that required students to apply theoretical concepts, interpret spectra from the techniques studied, and solve logic-based problems. Given the cumulative nature of the course, each assessment progressively incorporated content from earlier topics. An example of the first assessment is provided in the Supplementary Material.

After the first assessment, students completed an anonymous brief survey designed to evaluate the effectiveness of the protocols, focusing on their impact on confidence of the students during the exam and their motivation to study in advance. The questionnaire consisted of two statements evaluated on a 5-point Likert scale, where students could express their level of agreement ranging from "strongly disagree" (1) to "totally agree" (5). The statements were as follows:

(a) The protocol motivated me to study for the exam earlier.
(b) Having the protocol in hand made me feel more at ease for the exam.

The collected data was essential for monitoring the ongoing development of the activity, allowing the professor to make necessary adjustments for future assessments. At the end of the semester, a final questionnaire, similar to the previous one, was applied and included the following statements:

(a) I faced no difficulties in preparing the protocols.
(b) Preparing the protocols prompted me to reflect on the course content.
(c) Preparing the protocols contributed to my understanding of the course content.
(d) The protocols I prepared helped me in answering the exam questions.

RESULTS AND DISCUSSION

Student engagement and procedures development

To provide an overview of student engagement and their approach to the activity, we first describe general participation trends and then highlight an example of student work. Figure 3a illustrates the number of students who engaged in each of the three protocols, while Figure 3b lists those who submitted protocols in advance for the assistant professor to review. Significantly, every student completed at least one of the assigned protocols.

Overall, student participation ranged from 20 to 23 students, peaking during the first assessment and remaining steady throughout the term. However, there was a noticeable drop in advance submissions for the third assessment, with only 5 students submitting protocols for review. This decrease may reflect increased academic demands and fatigue toward the end of the semester, making it harder for students to prepare material in advance. Alternatively, it is possible that by this point students had become more confident in understanding the expectations of the professor and felt less need for feedback, having adapted their work accordingly.

From a pedagogical standpoint, this decline suggests that the activity design could be refined to sustain engagement throughout the semester.[25] For instance, incorporating short, formative checkpoints or in-class peer-review sessions between assessments might encourage continuous participation and distribute the workload more evenly. Providing incremental incentives (such as partial credit for early submissions) could also motivate students to maintain consistent involvement. Additionally, explicitly discussing the evolving purpose of each protocol (from initial comprehension to refinement and integration of techniques) may help students perceive ongoing value in submitting their work for review, even in later stages of the course.

Figure 4 presents a logically structured protocol, originally prepared by a student at the beginning of the semester and later translated from Brazilian Portuguese to English. The protocol was designed to support problem-solving in mass spectrometry, specifically for the first assessment. After our analysis, it was divided into five sections. The student's original draft is available in the Supplementary Material.

The first section, titled General Workflow, demonstrates how the student simplified the process of interpreting a mass spectrum by breaking it down into clear, manageable steps. This approach transformed what could be a complex task into an organized, step-by-step method to be applied in any mass spectrum. The first section of this protocol was divided into four main steps:

(1) Molecular ion identification: the student begins by identifying the molecular ion, checking for presence or absence of isotope peaks that indicate the presence of bromine or chlorine atoms, and verifying nitrogen atoms if the molecular mass is odd.
(2) Reference consultation: using appendix A, "Formula Masses for various combinations of carbon, hydrogen, nitrogen and oxygen", from Silverstein's "*Spectrometric Identification of Organic Compounds*" book,[26] the student determines the molecular formula based on the molecular ion and calculates the hydrogen deficiency index.
(3) Structure proposal: possible structures are proposed based on the base peak and observed mass losses.
(4) Structure reevaluation: the student suggests reviewing the proposed structures to ensure logical consistency.

The subsequent sections provide complementary information to support each step outlined in the first section. Section II includes a table of common isotopes and their mass spectrum signals, which

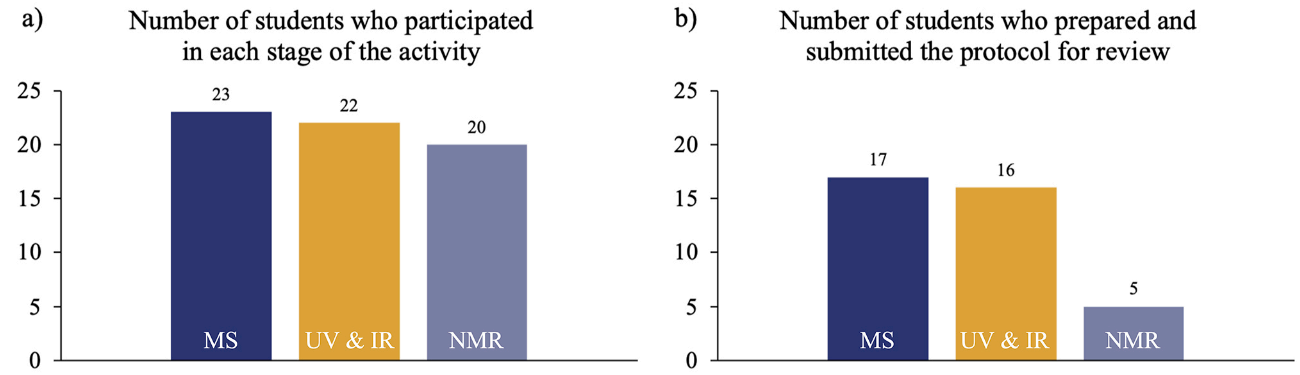
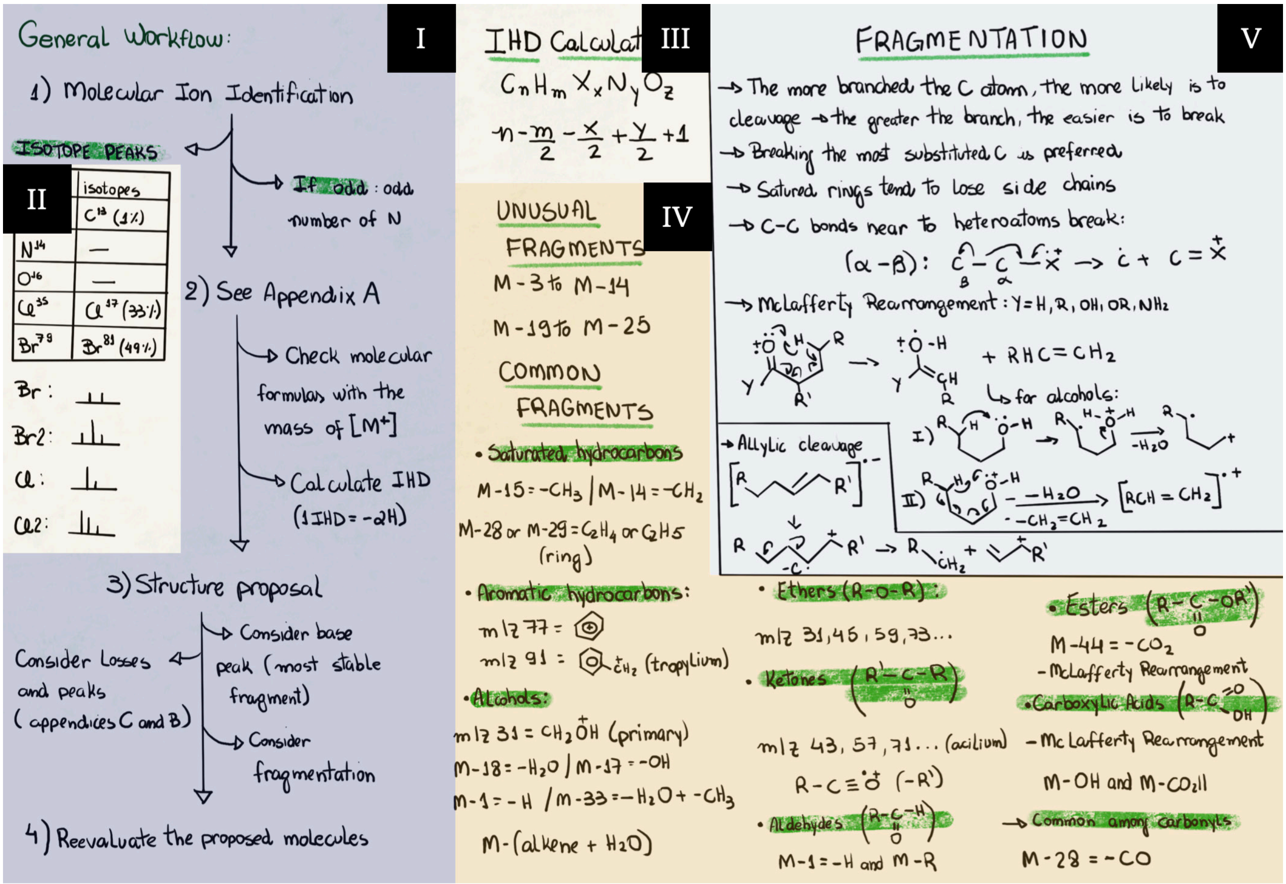


Figure 3. *(a) Number of students who participated in each of the three protocols; (b) number of students who submitted protocols in advance for review by the assistant professor (n = 25)*



General Workflow:

1) Molecular Ion Identification

ISOTOPE PEAKS

If odd : odd number of N

	isotopes
	C^{13} (1%)
N^{14}	—
O^{16}	—
Cl^{35}	Cl^{37} (33%)
Br^{79}	Br^{81} (49%)

Br :
Br2:
Cl :
Cl2:

2) See Appendix A

Check molecular formulas with the mass of $[M^+]$

Calculate IHD (1 IHD = −2H)

3) Structure proposal

Consider Losses and peaks (appendices C and B)

Consider base peak (most stable fragment)

Consider fragmentation

4) Reevaluate the proposed molecules

IHD Calculat

$C_nH_mX_xN_yO_z$

$n-\frac{m}{2}-\frac{x}{2}+\frac{y}{2}+1$

UNUSUAL FRAGMENTS

M − 3 to M − 14

M − 19 to M − 25

COMMON FRAGMENTS

- Saturated hydrocarbons

$M-15=-CH_3$ / $M-14=-CH_2$

M-28 or M-29 = C_2H_4 or C_2H_5 (ring)

- Aromatic hydrocarbons:

m/z 77 =

m/z 91 = (tropylium)

- Alcohols:

m/z 31 = $CH_2\overset{+}{O}H$ (primary)

$M-18=-H_2O$ / $M-17=-OH$

$M-1=-H$ / $M-33=-H_2O+-CH_3$

M-(alkene + H_2O)

FRAGMENTATION

→ The more branched the C atom, the more Likely is to cleavage → the greater the branch, the easier is to break

→ Breaking the most substituted C is preferred

→ Satured rings tend to lose side chains

→ C−C bonds near to heteroatoms break:

(α − β):

→ McLafferty Rearrangement : Y = H, R, OH, OR, NH_2

+ $RHC=CH_2$

↳ for alcohols:

I)

$-H_2O$

II)

$-H_2O$

$-CH_2=CH_2$

$[RCH=CH_2]^{\cdot +}$

→ Allylic cleavage

- Ethers (R-O-R):

m/z 31, 45, 59, 73...

- Ketones (R'−C−R)

m/z 43, 57, 71... (acilium)

$R-C\equiv\overset{\cdot +}{O}$ (−R')

- Aldehydes (R−C−H)

$M-1=-H$ and M − R

- Esters (R−C−OR')

$M-44=-CO_2$

- McLafferty Rearrangement

- Carboxylic Acids

- McLafferty Rearrangement

M-OH and M-CO_2H

→ Common among carbonyls

$M-28=-CO$

Figure 4. *Student-prepared mass spectrometry protocol (translated from Brazilian Portuguese and divided into five sections)*

can aid in identifying bromine or chlorine in the molecular ion by recognizing their distinct isotope peaks. Section III explains how to calculate the hydrogen deficiency index, a key step in determining potential degrees of unsaturation. Section IV lists the masses of absent fragments and common fragments associated with certain organic functional groups, helping to refine structure proposals by eliminating unlikely options and focusing on plausible fragment patterns. Finally, in section V, the student outlines the main rules of fragmentation, enabling adjustments to the proposal to better align with established fragmentation patterns.

General analysis of activity outcomes and practical implications

Figure 5 presents the questionnaire results obtained after the first assessment, focusing on the students who prepared the protocols. Overall, the findings indicate a positive response to the activity, with 15 out of the 23 participants reporting increased motivation to study in advance (Figure 5a). These students cited the protocol activity as a key factor, suggesting that the structured approach helped them better manage their study time and feel more prepared. The remaining students, except for one, were neutral about the effect of the activity on motivation, possibly indicating varied personal study habits or a lesser perceived need for structured review.

Regarding emotional experience of the students during the assessment, 13 out of 23 students agreed that having their own protocol on hand made them feel more at ease during the test (Figure 5b). This suggests that preparing and consulting their own material may have provided a sense of reassurance for about half of the class, as it allowed them to rely on personally constructed reference guides rather than solely on memory. For these students, the opportunity to use their own protocols possibly reduced uncertainty and helped them focus on problem-solving rather than recalling isolated facts.

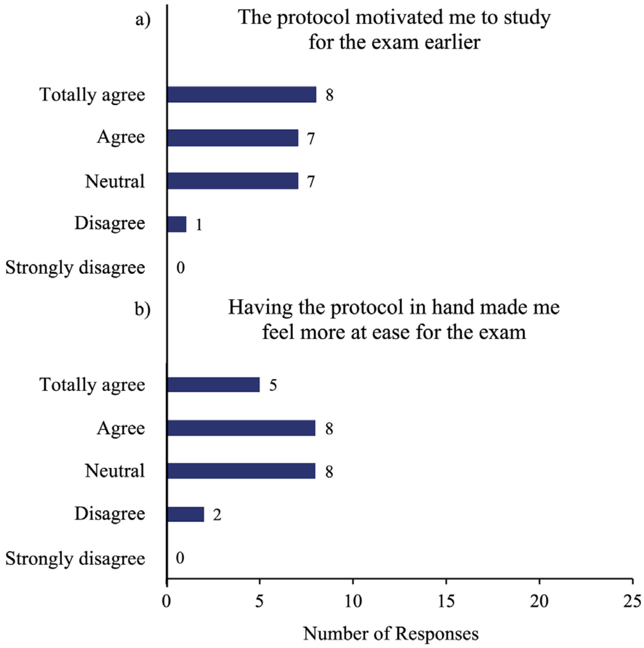


Figure 5. *Response distribution from the first questionnaire on the activity's impact on students' confidence and motivation to study in advance (n = 23)*

In contrast, the other students either disagreed or remained neutral, indicating that the availability of the protocols did not noticeably lessen their anxiety or alter their exam experience. This response may be related to individual differences in study habits, test-taking confidence, or familiarity with open-material assessments. Since the questionnaire was completed after the first assessment, these perceptions appear to have been shaped by comparisons with previous experiences in traditional courses, where personal materials are typically not allowed during exams. Consequently, the sense of ease reported by some students may reflect both the novelty of the activity and the degree of self-efficacy each student brought to the task.

Figure 6 displays the results from the follow-up questionnaire administered to the entire class at the end of the course, after the final exam, as all students had prepared at least one protocol. The questionnaire focused on the challenges students faced while developing the protocols. A total of 16 students reported no significant difficulties (Figure 6a), indicating that the majority found the task manageable, potentially due to their familiarity with the content. However, one student found it challenging to sketching and structuring detailed information into concise protocols, highlighting a common struggle in synthesis and deconstruct skills. This observation aligns with findings in educational psychology, which indicate that applying and analyzing are considered higher-order skills within Bloom's taxonomy and require consistent practice to develop effectively.[27]

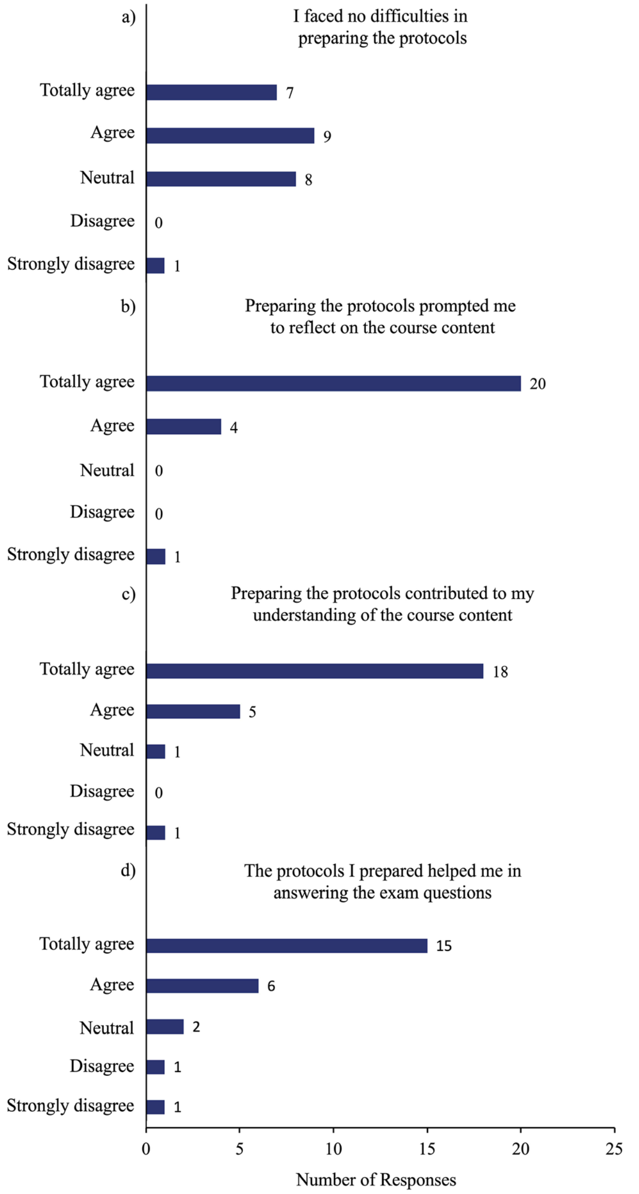


Figure 6. *Response distribution from the final questionnaire on the activity's impact on students' experiences with preparing and utilizing protocols (n = 25)*

Regarding the activity's role in encouraging deeper content reflection, 20 out the 25 students agreed that preparing protocols helped them reflect on the material (Figure 6b). This outcome supports Galbraith's (1999)[18] assertion that writing activities prompt students to revisit and reinforce conceptual knowledge. The four students who partially agreed and one who disagreed might reflect individual differences in learning preferences or perhaps a need for additional support in developing reflection skills through Writing-to-Learn activities.

Students were also asked to evaluate the effectiveness of the protocol-preparation in supporting their understanding of Organic Compound Analysis (Figure 6c). Eighteen students agreed that the activity facilitated learning, while five partially agreed, one was neutral, and one disagreed. This generally positive response underscores the role of the protocol in aiding comprehension, likely by helping students organize complex information and reinforcing key concepts. However, the partial agreement and neutral responses suggest that for some students, additional instructional scaffolding could enhance the utility of the protocol in their learning process.

The proportion of students who remained neutral or disagreed with statements related to motivation (Figure 5b) or the ease of synthesizing information (Figure 6a, 6c) highlights individual learning differences. These responses may stem from diverse study preferences or from the inherent complexity of organic spectroscopy (particularly NMR interpretation), which demands integrating multiple data sources and managing a higher cognitive load. In this sense, while the activity successfully promoted engagement and reflection for most students, some may have required additional instructional support. Future implementations could incorporate structured guidance, such as stepwise examples or guided templates, to help students with different learning profiles fully benefit from the protocol-development process.

Finally, the questionnaire asked whether the protocols were helpful in solving the exam questions (Figure 6d). The responses were predominantly positive, with 21 out of 25 students agreeing that the protocols assisted them during the exam. This strong agreement suggests that the activity effectively supported students in recalling and applying course content. Although a small number of students did not perceive the protocols as helpful, this may reflect individual differences in study habits or exam strategies. Overall, the results indicate that protocol preparation was a valuable tool for most students during the assessment.

CONCLUSIONS

The implementation of protocol-preparation as an active learning strategy in the Organic Compounds Analysis course demonstrated potential benefits for enhancing understanding of the students of spectroscopic techniques, while simultaneously promoting more structured study habits and reducing test anxiety. By engaging in the creation and refinement of protocols, students were provided with the opportunity to break down intricate content into manageable steps, thus encouraging a more thorough conceptualization of each technique. The combination of Computational Thinking strategies and Writing-to-Learn exercises allowed for a deeper reflection on course material, fostering the development of systematic approaches to structural elucidation.

Despite these outcomes, variability in responses of the students highlighted the need for further instructional scaffolding and individualized support. While most of the students reported increased motivation, deeper reflection, and a sense of preparedness for assessments, others experienced difficulties synthesizing and applying information or remained neutral to the perceived benefits of the protocols. Addressing these differences requires continued refinement of the activity, potentially incorporating more personalized feedback sessions, varied practice opportunities, and additional tools for building confidence in problem-solving scenarios.

Overall, the protocol-preparation activity illustrated how targeted, active learning methodologies can contribute to improved content comprehension, greater student engagement, and reduced assessment-related anxiety.

SUPPLEMENTARY MATERIAL

Example of assessment and original student draft response are available in http://quimicanova.sbq.org.br, in the form of PDF file, with free access.

DATA AVAILABILITY STATEMENT

All data supporting the findings of this study are included in the article.

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REFERENCES

1. Graulich, N.; *Chem. Educ. Res. Pract.* **2015**, *16*, 9. [Crossref]
2. Anderson, T. L.; Bodner, G. M.; *Chem. Educ. Res. Pract.* **2008**, *9*, 93. [Crossref]
3. Childs, P. E.; Sheehan, M.; *Chem. Educ. Res. Pract.* **2009**, *10*, 204. [Crossref]
4. Lieber, L.; Graulich, N.; *J. Chem. Educ.* **2020**, *97*, 3731. [Crossref]
5. Entwistle, N. J.; Thompson, J.; Wilson, J. D.; *Higher Education* **1974**, *3*, 379. [Crossref]
6. Zusho, A.; Pintrich, P. R.; Coppola, B.; *International Journal of Science Education* **2003**, *25*, 1081. [Crossref]
7. Cassady, J. C.; Johnson, R. E.; *Contemporary Educational Psychology* **2002**, *27*, 270. [Crossref]
8. Ellis, J. W.; *J. Chem. Educ.* **1994**, *71*, 399. [Crossref]
9. Angawi, R. F.; *J. Chem. Educ.* **2014**, *91*, 823. [Crossref]
10. Cardozo, L. T.; de Azevedo, M. A. R.; Carvalho, M. S. M.; Costa, R.; de Lima, P. O.; Marcondes, F. K.; *Advances in Physiology Education* **2020**, *44*, 744. [Crossref]
11. Cartrette, D. P.; Bodner, G. M.; *J. Res. Sci. Teach.* **2010**, *47*, 643. [Crossref]
12. Wing, J. M.; *Commun. ACM* **2006**, *49*, 33. [Crossref]
13. Nelson, N. In *Writing as a Learning Tool: Integrating Theory and Practice*, 1st ed.; Tynjälä, P.; Mason, L.; Lonka, K., eds.; Springer Dordrecht, p. 23-36.
14. Wing, J. M.; *Philos. Trans. R. Soc., A* **2008**, *366*, 3717. [Crossref]
15. Cansu, F. K.; Cansu, S. K.; *International Journal of Computer Science Education in Schools* **2019**, *3*, 17. [Crossref]
16. Rivard, L. O. P.; *J. Res. Sci. Teach.* **1994**, *31*, 969. [Crossref]
17. Hayes, J. R.; Flower, L. S. In *Cognitive Processes in Writing*, 1st ed.; Gregg, L. W.; Steinberg, E. R., eds.; Routledge: United Kingdom, 2016, p. 3-30.
18. Galbraith, D. In *Knowing What to Write: Conceptual Processes in Text Production*, 1st ed.; Torrance, M.; Galbraith, D., eds.; Amsterdam University Press: Amsterdam, The Netherlands, 1999, p. 139-159.
19. Klein, P. D.; *Educational Psychology Review* **1999**, *11*, 203. [Crossref]
20. Klein, P. D.; Boscolo, P.; *Journal of Writing Research* **2016**, *7*, 311. [Crossref]
21. Gupte, T.; Watts, F. M.; Schmidt-McCormack, J. A.; Zaimi, I.; Gere, A. R.; Shultz, G. V.; *Chem. Educ. Res. Pract.* **2021**, *22*, 396. [Crossref]
22. Finkenstaedt-Quinn, S. A.; Snyder-White, E. P.; Connor, M. C.; Gere, A. R.; Shultz, G. V.; *J. Chem. Educ.* **2019**, *96*, 227. [Crossref]
23. Schmidt-McCormack, J. A.; Judge, J. A.; Spahr, K.; Yang, E.; Pugh, R.; Karlin, A.; Sattar, A.; Thompson, B. C.; Gere, A. R.; Shultz, G. V.; *Chem. Educ. Res. Pract.* **2019**, *20*, 383. [Crossref]
24. Watts, F. M.; Schmidt-McCormack, J. A.; Wilhelm, C. A.; Karlin, A.; Sattar, A.; Thompson, B. C.; Gere, A. R.; Shultz, G. V.; *Chem. Educ. Res. Pract.* **2020**, *21*, 1148. [Crossref]
25. Kuh, G. D.; *Change: The Magazine of Higher Learning* **2003**, *35*, 24. [Crossref]
26. Silverstein, R. M.; Webster, F. X.; Kiemle, D. J.; Bryce, D. L.; *Spectrometric Identification of Organic Compounds*, 8th ed.; John Wiley & Sons: New Jersey, USA, 2014, p. 46-66.
27. Forehand, M. In *Emerging Perspectives on Learning, Teaching, and Technology*; Orey, M., ed.; Global Text: Zurich, 2010, p. 41-47.