

Promoting the Study of Inorganic Nomenclature in University Students through an Educational Strategy Using M-learning

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ABSTRACT

Herein, we explore the impact of using a flipped classroom approach on the achievement of learning outcomes in the International Union of Pure and Applied Chemistry (IUPAC) inorganic nomenclature in fundamental chemistry courses at the university level. In addition, the study sought to evaluate student attitude, motivation, and engagement when using this dynamic and interactive learning strategy. We assessed learning competencies through workshops and post-activity tests. To determine the effectiveness of this educational strategy, we compared the results between the experimental and control groups using the average scores from each assigned task. A total of 72 students participated in the activity, and non-probabilistic sampling was used to select the study population. In the activities, the students in the experimental group achieved higher average grades compared to those in the control group. 97.6% of students in the experimental group passed the final test, with grades ranging from 3.0 to 5.0 (where 5.0 equals 100%), whereas only 58.6% of the control group passed the final test. The statistical analysis of the classroom implementation results showed that using the inverted approach helped students learn key concepts and IUPAC nomenclature rules, enhancing their ability to identify and name different inorganic compounds. These findings also indicated that student-centered educational activities enhance competence, boost motivation, and improve subject understanding.

KEY WORDS: Active learning, experiential education, flipped classroom, fun learning ambience, inorganic nomenclature

INTRODUCTION

The study of inorganic nomenclature involves identifying and naming compounds according to the rules established by the International Union of Pure and Applied Chemistry (IUPAC). This is crucial for scientific communication, facilitating knowledge exchange, determining the safety of substances, and accurately documenting compounds used in various applications of chemistry, such as scientific research, pharmaceuticals, food, and cosmetics. Therefore, it is one of the fundamental elements of learning chemistry, allowing us to understand the structure and properties of compounds. First-year professors in various university programs often find it challenging to teach inorganic nomenclature due to the extensive amount of information involved. A review of the literature from the past 5 years reveals several teaching methods used to instruct this subject and reinforce its systematic rules. These methods include game-based learning, such as WErNEr, Molebots, and Ion Hunters. WErNEr is a card game where the objective is to build a compound over eight rounds using 8–10 cards, depending on the number of players (Buendía-Atencio et al., 2022). The second game is a level-based video game in which the player must capture as many molecules as possible by using a map to locate them. The player then needs to determine if the molecules are correctly named and if not, the molecules must be eliminated by shooting them with a laser gun. Interestingly,

this game was used to teach chemistry to students who did not receive any classroom instruction (Gupta, 2019).

The last game was designed to be played in pairs in the classroom. Students are required to name anions and cations, and the winner is the one who writes the highest number of ions on a board (Yenikalaycı et al., 2019). Mobile learning is also an important methodology, and there are various virtual platforms that offer free and paid versions of apps focused on the subject of inorganic nomenclature (Sousa Lima et al., 2019). According to studies by Manivel and collaborators, it is concluded that these apps serve as a supportive tool for constructive and meaningful learning. However, in order for them to be incorporated into the classroom, they require planned activities from the professor without overuse (Manivel Chávez et al., 2021). This study involved implementing a flipped classroom activity using m-learning with 1st-year undergraduate chemistry students. The main goal was to share the experience of using the flipped classroom method to teach inorganic nomenclature. The students were introduced to the platform in class, used it outside of class, and then engaged in active learning with the professor during face-to-face sessions. In a flipped classroom, traditional student and professor roles are reversed, with students studying theoretical content online and engaging in student-centered activities in the classroom for feedback. The flipped classroom is an appealing choice for university educators because it enables them to optimize

classroom time by addressing individual concerns. Students have more autonomy and flexibility in their learning process (Fisher et al., 2020). This approach promotes active classes and collaborative work and aligns with the needs of a digitally connected environment, catering to the preferences of new generations (Gallagher, 2023). To ensure an effective flipped classroom experience, several factors need to be considered. These include designing pre- and post-class activities, selecting appropriate digital tools and content for learning, and understanding the impact of the new methodology on students (Poulain et al., 2023). In a study on a Mathematics for Engineers course, some students struggled to adapt their study habits to the flipped classroom model. They lacked motivation to watch instructional videos and encountered issues with group activities due to some members' lack of commitment. This resulted in a frustrating experience for some students (Nielsen, 2023).

These challenges make incorporating the flipped classroom approach even more difficult for professors. When designing and structuring activities for a flipped classroom, some authors suggest that during synchronous sessions, it is important to focus on student-centered learning activities. These activities may include problem-solving, quizzes, games, concept maps, and practical exercises. According to the literature, these methods have been shown to improve students' understanding of the subject compared to traditional teaching methods (Bessas et al., 2024; Deepak et al., 2023; Robert et al., 2016; van Alten et al., 2019). An emerging trend in asynchronous sessions involves using online technologies (Casselmann et al., 2021) and resources with easily accessible learning materials for students (Seery, 2015). It is important to properly design preliminary or instructional activities, as they play a fundamental role in the construction of learning (Eichler, 2022; Okafor, 2022).

The following are some scenarios of chemistry teaching and activities implemented using the flipped classroom: in a first-semester organic chemistry course, traditional lectures were replaced by short videos, only accessible to students. During face-to-face class time, students engaged in problem-solving, peer-led discussions, and mini-lectures (Mooring et al., 2016). An observational study of seven undergraduate organic chemistry courses was conducted over a 5-year period. These courses used face-to-face lectures to develop modules, with guidance from a student assistant and an advanced student. These modules were reviewed, and feedback was provided. In addition to lectures, out-of-class videos explaining basic organic chemistry concepts were used, along with quizzes (Holloway et al., 2024). In a senior undergraduate physicochemistry course, video lectures and exercise workshops were utilized before class. The just-in-time teaching method was then implemented in class, followed by group work on activities created by the Authors (Gomez et al., 2025). In an analytical chemistry class, first-semester undergraduate students in biomedical sciences participated in various activities. The students attended classroom lectures on emission spectroscopy, absorbance, mass, and nuclear magnetic

resonance. In addition, they learned about chromatography and electrophoresis through videoconferences, with an online blog used for posting questions moderated by the professor. They also took part in a workshop conducted in person, with the support of a monitor and guidance from the professor (Ponikwer and Patel, 2018). During a biochemistry seminar for second-semester medical students titled "From Gene to Protein," a Flipped Classroom approach, with video support and comprehension questions, was utilized. The students were divided into three homogeneous groups, each provided with different work materials and instructions for the self-learning phase (Kühl et al., 2019).

In previous descriptions, it is common to present classes in video format, usually using a whiteboard or a screen capture of a PowerPoint presentation. However, these options have some disadvantages that can be overcome with the use of a lightboard. The lightboard optimizes student-professor interaction and visualization of the content (Fung, 2017). Its use is already reported in general chemistry classes, and it is described as an attractive environment for understanding abstract concepts such as chemical reactions and molecular structures (Rojas, 2023).

In this study, we aimed to conduct instructional activities, face-to-face interactions, and self-learning activities with utmost rigor. For the instructional activities, we conducted socialization, administered questionnaires, provided feedback, and utilized ludic alternatives. For the self-learning stage, we chose to use m-learning to access educational content.

METHODOLOGY

Participants and Study Design

This experience of educational innovation was conducted with students enrolled in fundamental chemistry courses at Universidad del Cauca (Popayán, Colombia), following the field guide defined by Poulain et al. (Poulain et al., 2023). The participants were selected through non-probabilistic sampling ($n = 72$), which means that accessible cases were chosen based on their availability to be included in the research (Kim, 2022). As a crucial element in designing the interactive materials for our study, we carefully assessed the learning style preferences of our study population, drawing on established previous research to guide our approach (Table S1; Figures S1 and 2, supplementary information). This quasi-experimental study followed a structured three-stage process: design, implementation, and evaluation. The data collected at each stage of this work was used solely for research purposes. From the beginning, this study received approval from our university's ethics committee. Students and researchers participated by signing an informed consent form, which outlined a confidentiality agreement regarding their participation in this research activity.

Design

We use Genially, a cloud-based free tool, to create visual teaching resources for students to help them learn inorganic

compound nomenclature (Table S2, SI). These interactive and dynamic platforms are easy to navigate and allow students to learn different functional groups at their own pace. Each platform contains four sections: structure, name, examples, and challenges, which are enabled sequentially (Figure 1).

On the start screen (Figure 1a), when you click on the blue “start” button, a base screen appears with sections to explore (Figure 1b). To begin, the student needs to enable the first section and explore its contents step by step. Once they finish, they will be transferred to another screen where the second section is activated, and so on until the end. In the first section, students can find information about the structure and concepts of chemical formulation (Figure 2a), and in the second section, they can learn about different types of nomenclature and their respective rules (Figure 2b). The content in each tab is summarized and presented in a didactic and user-friendly manner so that students can explore without any difficulty.

In the last two sections, there are practice exercises. In the first section, the student can refer to nine representative examples of molecules. For each molecule, its name is presented in three types of nomenclature: systematic, stock, and traditional (Figure S3, SI). This allows the student to compare and identify similarities and differences between the rules. The last section includes a series of exercises that the student must complete to advance. To progress, the student must answer the questions correctly. After answering, the next screen is activated, and the student will have to complete nine exercises – three for each type of nomenclature (Figure S4, SI).

Implementation

In our study, we aimed to create a structured timeline for the flipped classroom strategy that emphasizes active student involvement in both pre-class preparation and face-to-face

activities (Table 1), taking into account the different levels of cognitive domains outlined in Bloom’s revised taxonomy (Anderson, 2001). Lower levels of the cognitive domain, such as remembering and comprehending, were covered by students outside of class time through pre-class materials and self-paced review (phase 1). In the classroom, during the face-to-face activities (phases 2 and 3), students focused on higher levels of cognitive work, such as applying, analyzing, evaluating, and creating (Subramaniam, 2016).

Evaluation

After finishing the second phase, the students underwent an evaluation test and filled out a satisfaction survey. The knowledge test was a multiple-choice test created on the Quizizz platform. The satisfaction survey was designed using a Google Form and was tested by the professor’s team before the start of the research to address potential language and comprehension errors (Figures S5-7, SI). The questionnaire on participant satisfaction was divided into three main sections. The first section, which assessed the graphical interface and functionality of the platform used in the pre-class activities, included five questions. Responses were rated on a Likert scale (Likert, 1932) with three levels: agree, partially agree, and not agree. The second section evaluated the quality, clarity, and relevance of the academic content provided on the Genially platforms for the flipped classroom activity and also included five questions. Participants were asked to rate their level of agreement with each statement according to the prescribed rating scale. The last section, which also comprised five questions, assessed the students’ perception of the academic proposal in terms of both operational and educational parameters. To confirm the effectiveness of the flipped classroom approach compared to traditional teaching methods, we conducted a statistical analysis using the Minitab



Figure 1: Genially platform screenshots: (a) start screen; (b) base content screen

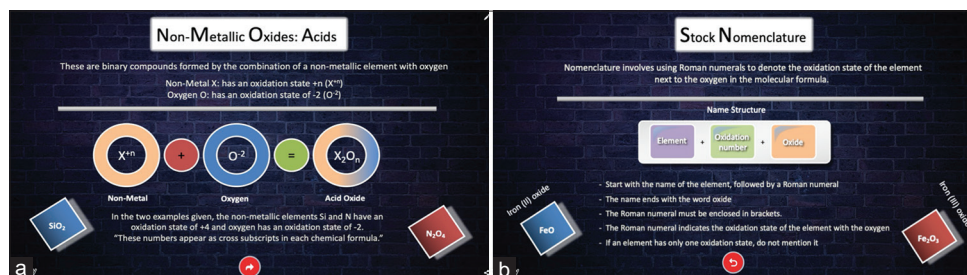


Figure 2: Screenshot examples: (a) chemical formulation; (b) naming rules and structure

18 software. We performed a Welch's t-test on the average data (class grades) from both the experimental and control groups, using a confidence level of 95% ($p < 0.05$).

RESULTS

The research project used a quasi-experimental design with three groups enrolled in fundamental chemistry courses at Universidad del Cauca (Popayán, Colombia): an experimental team (Groups 1 and 2) and one control team (Group 3). In the study, there were 72 students, consisting of 40.3% male, 55.5% female, and 4.2% identifying as LGBTIQ. The average age of the students ranged from 17 to 20 years old (Table 2).

To evaluate the impact of the flipped classroom methodology on learning inorganic compound nomenclature, we conducted a multiple-choice post-test that compared the results of all

Table 1: Phases and actions of the proposed flipped classroom approach

Phase	Moment	Activities	Time
0	Synchronous	Socialization Characterization Signing informed consent	1 h
1	Asynchronous	Acid and basic oxides (G_1)* Inorganic bases (G_2)* Inorganic acids (G_3)*	As required
2	Synchronous	Group feedback Workshop Professor feedback	2 h
3	Synchronous	Workshops' results presentation Knowledge test Satisfaction surveys	1 h

*Interactive material supported by the Genially platform that students explore

Table 2: Working groups and sample distribution

Group	Status	Participant students	Gender type		
			Male (%)	Female (%)	LGBTIQ (%)
1	Experimental	21	40.3	55.5	4.2
2	Experimental	22			
3	Control	29			
Total		72		100	

students: experimental versus control team. The experimental team (Groups 1 and 2) received instruction using the flipped classroom method, whereas the control team (Group 3) followed traditional teaching methods without access to genially educational tools. Statistical analysis validated the differences in results between groups. In addition, we conducted surveys to assess the effectiveness of our teaching strategy and educational tools. The detailed findings and their implications for the success of this research are presented below.

Evaluation of Acquisition of Inorganic Nomenclature Competencies

Monitoring the learning objectives and competencies achieved by the students was essential for assessing the success of the activity. Following the synchronous meetings, all students involved in the study completed an evaluation test on the inorganic nomenclature of compounds. This included the experimental team (Groups 1 and 2) and one control team (Group 3). The evaluation test, which was conducted using an open-access gaming environment such as Quizziz, consisted of 10 multiple-choice questions with a single answer (Figures S5 and 6, SI). This allowed us to compare the differences in learning between the proposed active learning methodology and traditional classroom teaching. The results indicate that students participating in the flipped classroom activity achieved higher scores on the knowledge test than those in the control group (Figure 3).

In the experimental team (Groups 1 and 2), 42 students passed the test (97.7%), with 39.5% (17 students) achieving a perfect score. In addition, 23.2% (10 students) scored 4.5, and 20.9% (nine students) scored 4.0 (Figure 3a). In contrast, only 58.6% of the control team (Group 3) passed the test, and very few students achieved high scores. The more representative results for the control team were as follows: 17.2% (five students) scored 3.5, and 27.6% (eight students) scored 3.0 (Figure 3b).

Effectiveness of the Flipped Classroom Approach through Statistical Analysis

By consolidating and comparing the average scores of the experimental team (Groups 1 and 2) with those of the control team (Group 3), a statistical analysis was conducted to identify the differences between the flipped classroom model and traditional educational strategies used for teaching

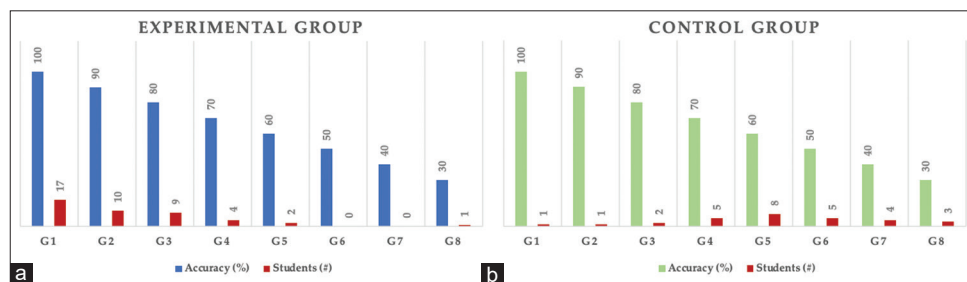


Figure 3: Results of the knowledge test on inorganic nomenclature conducted on the Quizziz platform for: (a) experimental team (Groups 1 and 2); (b) control team (Group 3)

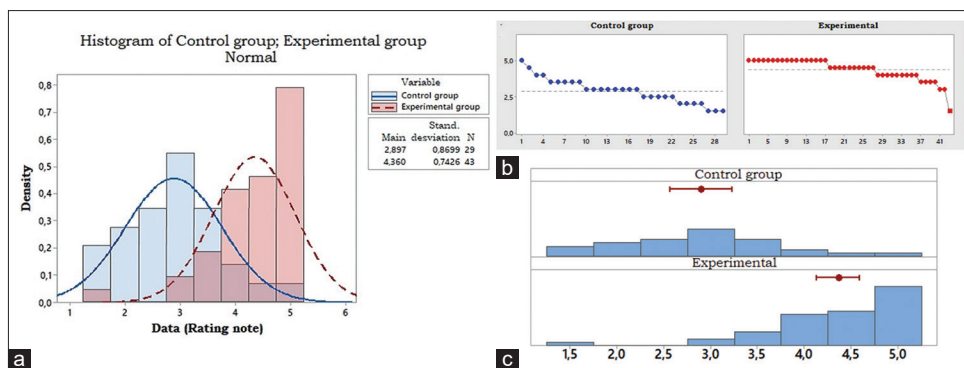


Figure 4: Statistical data of the Welch's t-test for experimental and control groups: (a) histogram; (b) distribution data referent to the mean; (c) mean standard deviation

inorganic nomenclature. Using Minitab software, a Welch's t-test was performed on the mean classroom grades of both groups. Figure 4 illustrates the histogram, the distribution data related to the mean, and the mean, standard deviation of the participants in this research.

Table 3 displays the statistical data for Welch's t-test, which is applicable in this case due to the lack of homogeneity between groups. The experimental team (Groups 1 and 2), consisting of 43 students, achieved a mean score of 4.36 on their tests, whereas the control team (Group 3), with 29 students, had a mean score of 2.89. This indicates a significant difference, suggesting that the flipped classroom teaching methodology had a positive impact on the students' learning processes.

To analyze the statistical difference between the means of the groups studied, we obtained the following data (Table 4). The difference between the means is 1.464, indicating that the mean of the experimental students is greater than that of the control students. To strengthen our findings, we performed a null hypothesis test to determine whether the means of the experimental and control groups significantly differ, using a significance level of 0.05:

- H_0 : Mean (experimental group) – mean (control group) = 0
- H_1 : Mean (experimental group) – mean (control group) \neq 0.

With a p-value of 0, we concluded that the mean scores of the experimental team (Groups 1 and 2) were significantly higher than those of the control team (Group 3), demonstrating considerable differences between the teaching methods implemented in this study.

Validation of the Educational Tool for Implementing Academic Strategy

To evaluate the effectiveness of our academic strategy, we had participating students complete a guided survey. They were asked to indicate their level of agreement with a series of questions related to three key aspects: functionality/graphical interface, content relevance, and student perception (Tables 5-7).

Table 5 displays the questions used to assess the tools' feasibility regarding functionality and graphical interface. The students' agreement or disagreement was measured using

Table 3: Difference between both experimental and control groups with Welch's t-test

Variable	n	Mean	Standard deviation	Standard error of the mean	IC of 95%
Experimental group	43	4.36	0.743	0.113	4.1319; 4.589
Control group	29	2.89	0.870	0.162	2.566; 3.227

Table 4: Results of the statistical tests for the null hypothesis

Difference	IC of 95%	Standard deviation grouped	Freedom degrees	T-value	p-value
1.464	1.8596; 1.082	0.796	70	7.65	0

a Likert scale with three possible responses: agree, partially agree, and not agree. The average results for the experimental students (Groups 1 and 2) revealed that the students had very positive perceptions about the design and usefulness of the educational platform, as shown in Table 5. For all questions from Q1 to Q5, there were high percentages of "agree" (62.8–88.4%) and "partially agree" (11.6–41.9%) responses. None of the students surveyed selected the "not agree" option for questions Q1, Q2, and Q4, indicating a high level of agreement. There were some negative responses for questions Q3 and Q5, but since only a few students responded this way, we do not consider these responses statistically significant. By analyzing these trends and understanding the intent of each question, we can confidently conclude that there is a clear acceptance of the platform's functionality for learning inorganic nomenclature according to IUPAC rules.

The relevance and appropriateness of the content on the inorganic nomenclature platform were assessed based on the organization of concepts, explanation of rules, examples, and proposed exercises. Acceptance and trends were analyzed using another five questions (Table 6). Similar to the previous evaluation parameter, the participating students had very positive perceptions. They responded with high levels of

Table 5: Evaluation of interactive tools for flipped classroom approach: graphical interface and functionality. Guiding questions Q1-Q5 (left); Graphical responses to the guiding questions (right)

Questions	Graphical interface and functionality																								
Q1. The graphic design and work environment always turned out to be pleasant.	<table border="1"> <caption>Data for Table 5 Graphical interface and functionality</caption> <thead> <tr> <th>Survey Question</th> <th>Not Agree (%)</th> <th>Partially Agree (%)</th> <th>Agree (%)</th> </tr> </thead> <tbody> <tr> <td>Q1</td> <td>0</td> <td>16.6</td> <td>81.4</td> </tr> <tr> <td>Q2</td> <td>0</td> <td>11.6</td> <td>88.4</td> </tr> <tr> <td>Q3</td> <td>6.9</td> <td>41.9</td> <td>51.2</td> </tr> <tr> <td>Q4</td> <td>0</td> <td>20.9</td> <td>79.1</td> </tr> <tr> <td>Q5</td> <td>4.6</td> <td>32.6</td> <td>62.8</td> </tr> </tbody> </table>	Survey Question	Not Agree (%)	Partially Agree (%)	Agree (%)	Q1	0	16.6	81.4	Q2	0	11.6	88.4	Q3	6.9	41.9	51.2	Q4	0	20.9	79.1	Q5	4.6	32.6	62.8
Survey Question		Not Agree (%)	Partially Agree (%)	Agree (%)																					
Q1		0	16.6	81.4																					
Q2		0	11.6	88.4																					
Q3		6.9	41.9	51.2																					
Q4	0	20.9	79.1																						
Q5	4.6	32.6	62.8																						
Q2. The instructions for exploring the educational platform were clear and precise.																									
Q3. The buttons and hyperlinks on the platform functioned properly.																									
Q4. The language used was easy to understand for interacting with the educational platform.																									
Q5. The educational platform provided enabled the deployment of functions to meet their expectations.																									

Table 6: Evaluation of interactive tools for flipped classroom approach: content relevance. Guiding questions Q6-Q10 (left); Graphical responses to the guiding questions (right)

Questions	Content relevance																								
Q6. The presentation order of each section facilitates learning inorganic nomenclature.	<table border="1"> <caption>Data for Table 6 Content relevance</caption> <thead> <tr> <th>Survey Question</th> <th>Not Agree (%)</th> <th>Partially Agree (%)</th> <th>Agree (%)</th> </tr> </thead> <tbody> <tr> <td>Q6</td> <td>2.3</td> <td>30.2</td> <td>67.5</td> </tr> <tr> <td>Q7</td> <td>2.3</td> <td>25.6</td> <td>72.1</td> </tr> <tr> <td>Q8</td> <td>4.7</td> <td>25.4</td> <td>72.1</td> </tr> <tr> <td>Q9</td> <td>4.7</td> <td>20.9</td> <td>74.4</td> </tr> <tr> <td>Q10</td> <td>0</td> <td>18.6</td> <td>81.4</td> </tr> </tbody> </table>	Survey Question	Not Agree (%)	Partially Agree (%)	Agree (%)	Q6	2.3	30.2	67.5	Q7	2.3	25.6	72.1	Q8	4.7	25.4	72.1	Q9	4.7	20.9	74.4	Q10	0	18.6	81.4
Survey Question		Not Agree (%)	Partially Agree (%)	Agree (%)																					
Q6		2.3	30.2	67.5																					
Q7		2.3	25.6	72.1																					
Q8		4.7	25.4	72.1																					
Q9	4.7	20.9	74.4																						
Q10	0	18.6	81.4																						
Q7. Each hyperlink should display relevant and easily readable information: text, graphics, and inorganic nomenclature rules.																									
Q8. The examples provided in the sections are clear and helpful in reinforcing learning.																									
Q9. The exercises presented in each challenge have been relevant for facilitating your learning process.																									
Q10. The tools used for playful learning strategies provide high-quality content presentation.																									

Table 7: Evaluation of interactive tools for flipped classroom approach: student's perception. Guiding questions Q11-Q15 (left); Graphical responses to the guiding questions (right)

Questions	Student's perception																								
Q11. It was motivating to use the educational tools supported by the Genially platform.	<table border="1"> <caption>Data for Table 7 Student's perception</caption> <thead> <tr> <th>Survey Question</th> <th>Not Agree (%)</th> <th>Partially Agree (%)</th> <th>Agree (%)</th> </tr> </thead> <tbody> <tr> <td>Q11</td> <td>0</td> <td>18.6</td> <td>81.4</td> </tr> <tr> <td>Q12</td> <td>2.3</td> <td>16.3</td> <td>81.4</td> </tr> <tr> <td>Q13</td> <td>2.3</td> <td>32.6</td> <td>65.1</td> </tr> <tr> <td>Q14</td> <td>0</td> <td>11.6</td> <td>88.4</td> </tr> <tr> <td>Q15</td> <td>2.3</td> <td>16.3</td> <td>81.4</td> </tr> </tbody> </table>	Survey Question	Not Agree (%)	Partially Agree (%)	Agree (%)	Q11	0	18.6	81.4	Q12	2.3	16.3	81.4	Q13	2.3	32.6	65.1	Q14	0	11.6	88.4	Q15	2.3	16.3	81.4
Survey Question		Not Agree (%)	Partially Agree (%)	Agree (%)																					
Q11		0	18.6	81.4																					
Q12		2.3	16.3	81.4																					
Q13		2.3	32.6	65.1																					
Q14	0	11.6	88.4																						
Q15	2.3	16.3	81.4																						
Q12. Values interactive tools with a high level of satisfaction to enhance their learning experience.																									
Q13. Playful tools have been crucial in achieving learning goals in naming inorganic compounds.																									
Q14. I would recommend this educational platform to other students as a valuable learning tool.																									
Q15. I would use the educational platform again as a learning tool.																									

acceptance to the proposed questions. For all items, the answers were either “agree” (67.5–81.4%) or “partially agree” (18.6–30.2%). Although, there were some negative answers and disagreements in some of the questions (2.3–4.7%).

The low percentage of these responses compared to the positive ones suggests that they are not very representative. The above results and trends indicate that the structure, order, and layout of the contents were very well-received by the users of the educational tool and were essential in reinforcing their learning. In the final section of the guided survey, we evaluated the students' behavior and their perspectives on the proposed activity as well as its development with the educational platform. The level of approval was evaluated through five guiding questions designed to measure their motivation, commitment, and satisfaction while studying with this methodology (Table 7). In general terms, the students had

very positive perceptions about the benefits of the platform. The results for the experimental team (Groups 1 and 2) show a high level of acceptance. For all the questions Q11 to Q15, the answers “agree” (65.1–81.4%) and “partially agree” (11.6–32.6%) stand out. These results indicate that the students found the activity highly enjoyable and were highly satisfied with their learning process.

Based on the results presented in the previous table, we want to emphasize the responses to questions Q11 to Q13. These aimed to evaluate the increase in student motivation, their level of satisfaction, the effectiveness of the methodology, and the adaptability of the educational platforms used as active learning strategies. The results for these three items are as follows: Q11 – agreement (81.4%), Q12 – agreement (81.4%), and Q13 – agreement (65.1%) and partial agreement (32.6%). The results are highly positive and align with existing literature.

Multiple studies in cognitive psychology have demonstrated that students experience improved information processing, motivation, and retention in STEM courses when utilizing metacognition and active learning techniques (D'Souza and Rodrigues, 2015; Freeman et al., 2014; Landa Cavazos and Ramírez Sánchez, 2018).

DISCUSSION

Learning supported by flipped classroom methodologies offers the advantage of incorporating a variety of activities for effective implementation. However, professors face the challenge of doing this effectively while considering students' priorities, learning objectives, and available tools. As mentioned, the interactive materials were hosted on the Genially platform, allowing each student to access them from their mobile devices and follow the study instructions provided. Professors must adapt to the technological realities of their students and utilize these tools appropriately to enhance interaction and engagement. Mobile devices are valuable tools for education, enabling users to easily access the internet and obtain a vast amount of information instantly. For this study, the content was developed directly from online resources using the software provided by the platform. Integrating technological development with education is essential, particularly for professors who may not have expertise in programming languages (Louw and Sanford-Dolly, 2024). Moreover, cell phones are widely accepted by students as a valuable resource for communication, relationship-building, and interaction. It helps develop their digital skills, autonomy, and time management. In a learning process that does not involve direct professor presence, educational resources are essential for placing the student at the center of their learning. M-learning combines this approach, offering flexibility while allowing for direct interaction with the instructor. Students expressed positive feedback regarding their use of the educational platform for learning inorganic nomenclature. They appreciated the organization of the content, the clarity of the examples, and the relevance of the exercises provided. The content was organized into four sections: structure, name, examples, and challenges. Following the format of previous reports, these sections were presented consecutively and interactively on a free-access platform. Genially facilitated the creation of a friendly work environment. It was an enjoyable and easy-to-explore tool that allowed students to engage with and review academic content through autonomous learning in their university education (Arteaga Fuertes et al., 2023).

The integration of hands-on exercises using systematic, traditional, and stock nomenclature enables students to effectively compare and contrast various naming systems, promoting a deeper understanding of the material.

The high levels of acceptance indicate that students regard the platform as a valuable tool for enhancing their learning. This positive perception is crucial because student motivation and engagement significantly contribute to successful learning

outcomes. Since students could access the main content outside of class, they had more time to engage in active learning strategies during synchronous sessions. These strategies included problem-solving, quizzes, and collaborative tasks and have proven to yield a deeper understanding of the learning objectives, significantly more so than traditional instructional approaches (Arteaga et al., 2025; Buitrago et al., 2023; Chang-Tik et al., 2024; Chau and Cheung, 2018; Gómez Buitrago et al., 2024). The experimental team (Groups 1 and 2) achieved higher average grades than the control team (Group 3), suggesting that the active learning environment improved students' understanding and retention of inorganic nomenclature. This finding aligns with other studies that support the advantages of the flipped classroom model in enhancing student success (Baig and Yadegaridehkordi, 2023; Campillo-Ferrer and Miralles-Martínez, 2021; Hao and Fang, 2024).

The findings of this study have important implications for chemistry professors. The successful implementation of the flipped classroom model indicates that similar approaches could be beneficial in other areas of science education. Educators are encouraged to adopt active learning strategies and utilize technology to create engaging learning environments that prioritize student-centered learning. Future research could focus on longitudinal studies to evaluate the long-term retention of knowledge gained through flipped classroom methodologies. In addition, investigating the impact of various types of pre-class materials, different technologies, and instructional strategies on student learning could provide valuable insights and contribute to a broader understanding of their effectiveness.

CONCLUSION

Our academic proposal, supported by results, has proven to be an effective approach to enhancing the teaching of inorganic compound nomenclature through the flipped classroom strategy. The creation of interactive content, use of freely available online tools, execution of active learning activities, and overall methodology employed in our project have enabled participating students not only to gain disciplinary knowledge but also to develop interpersonal and systemic competencies. These include oral and written communication, analysis and synthesis capacity, self-criticism, adaptation to new situations, time management, creativity, and decision-making. Furthermore, these efforts have contributed to improving students' attitudes, motivation, and commitment to their education, directly impacting the academic results of fundamental chemistry subjects in the chemistry program at Universidad del Cauca (Popayán, Colombia) in a very positive manner. The study involved 72 students, with 43 in the experimental team (Groups 1 and 2) and 29 in the control team (Group 3). After comparing the results of academic tests between groups and statistically validating them with a Welch's t-test, it was found that the flipped classroom strategy significantly enhanced the experimental students'

understanding of nomenclature rules in inorganic compounds. The significant differences in the data demonstrate that our innovative active learning methodology effectively reinforced the learning objectives and enhanced the understanding of IUPAC nomenclature rules. The platform's design and interactive features not only facilitated learning about inorganic nomenclature concepts but also fostered a stronger connection to the educational strategy. Based on student feedback, our teaching approach was well-received and valued for its educational and engaging format. Satisfaction surveys on graphical and playful tool functionality, content presentation and relevance, and student user perception support the effectiveness of our methodology in maintaining student interest and enhancing their learning experiences.

ETHICAL STATEMENT

The material and results presented in this paper are part of a research project (ID-5503) funded by the Vice Rectorate for Research at the Universidad del Cauca (501100005682). The project has received approval from the institution's ethics committee for both its planning and execution. All participating students voluntarily signed an informed consent form that outlined the purpose of the research, ensured confidentiality, and clarified that the results and data would be used solely for academic and research purposes.

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CONFLICTS OF INTERESTS

No potential conflicts of interest were reported by the authors.

AUTHOR CONTRIBUTIONS

Conceptualization, D.A.; methodology, A.C.C.; software, D.A.; validation, A.C.C., P.G.B. and D.A.; formal analysis, D.A. and P.G.B.; investigation, A.C.C., P.G.B. and D.A.; resources, A.C.C.; data curation, D.A.; writing – original draft preparation, D.A. and P.G.B.; writing – review and editing, A.C.C.; visualization, P.G.B.; supervision, D.A.; project administration, A.C.C.; funding acquisition, A.C.C. and D.A.

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ELECTRONIC SUPPORTING INFORMATION

Learning Style Preferences in the Population Study

To identify the predominant learning preferences of students regarding sensory instructions, we created a survey consisting of 15 informal questions. We utilized the VAK model, which focuses on visual, auditory, and kinesthetic learning styles. The questions were presented in a random order. We used a rating scale for evaluation, which included the following options: (1) Sometimes, (2) Almost always, and (3) Always.

GENIALLY INTERACTIVE PLATFORMS

Considering the important elements offered by Genially as a free access tool, we design 3 interactive platforms as pedagogic material to facilitate inorganic nomenclature learning (Table S1).

Table S1: Statements to determine preferred sensorial instructions in student population

Learning styles	No	Questions
Visual	2	I prefer following written instead of spoken instructions.
	4	I remember things better when I see them in writing.
	7	I learn better from drawings, diagrams, and maps.
	9	I like reading and I read quickly.
Auditive	13	When I'm asked to spell out a word, I visualize it in my mind.
	1	I remember things better if I say them out loud.
	6	I enjoy learning when I have somebody that explains it to me.
	10	I prefer listening news from the radio.
Kinesthetic	12	I hear music on my cellphone, computer or through an electronic device.
	15	When I read in silence, I repeat the words to myself.
	3	When I study, I like to chew gum or eat something.
	5	I prefer to learn through drills, games, or dramatic plays.
	8	I enjoy working with my hands.
	11	I enjoy being close to others, and I like hugs.
	14	When I learn new concepts, I find myself acting or drawing.

LEARNING OBJECTIVES ASSESSMENT

To evaluate the skills acquired by the students' participants, a test consisting of ten multiple-choice questions with only one answer was applied to both the experimental and control group (Figure S5 and S6).

QUIZZIZ PLATFORM TESTING SCREENSHOT

Activity Validation

The academic strategy developed in the classroom was validated by participating students through three key aspects: the functionality of platforms, the content relevance, and the student's perception. This validation was conducted via a survey that assessed the students' levels of agreement or disagreement with various statements.

Table S2: Access links of inorganic nomenclature interactive platforms supported on Genially

Interactive tool	Access link
G ₁ . Acid and basic oxides	https://view.genial.ly/607a15c3c54e6b0d0da67b5f/interactive-content-v1-nomenclatura-inorganica-oxidos
G ₂ . Inorganic bases	https://view.genial.ly/609b462ff4ccb40d49690685/presentation-bases-inorganicas
G ₃ . Inorganic acids	https://view.genial.ly/607e240e43ba7b0cf4e10f6f/presentation-acidos-inorganicos

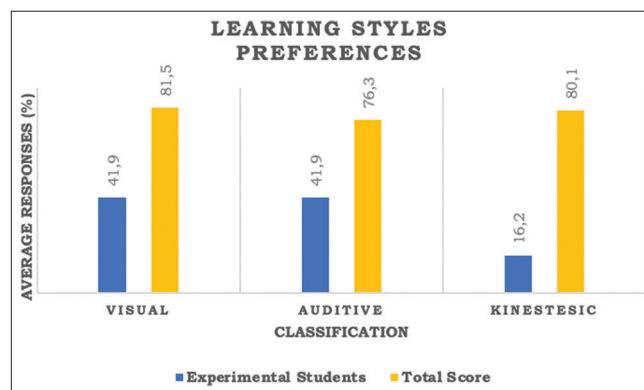


Figure S1: Graph for trends in students' instructional sensory preferences

No.	Student	Visual					Auditive					kinesthetic							
		Q2	Q4	Q7	Q9	Q13	TV	Q1	Q6	Q10	Q12	Q15	TA	Q3	Q5	Q8	Q11	Q14	TK
1	Mario Andres Ortega	1	2	2	1	3	9	1	1	1	3	2	8	1	1	2	3	3	10
2	Valentina Herrera Rozo	2	2	1	2	2	9	2	3	1	2	2	10	2	2	1	2	1	8
3	Saray Candelo	2	3	3	3	2	13	3	2	1	3	2	11	3	3	3	1	3	13
4	Javier Andres Quinayas	3	2	3	2	2	12	1	2	1	3	3	10	1	2	3	3	1	10
5	Juan Manuel Achipiz	2	1	2	1	1	7	2	2	1	3	1	9	1	2	1	3	1	8
6	Joan Alejandro Urbano	1	2	1	2	3	9	1	1	1	1	3	7	1	1	3	1	1	7
7	Sebastian Velasco Quisoboni	1	2	2	2	3	10	2	3	1	3	2	11	2	2	2	1	1	8
8	Jessika Narvaez	2	3	1	2	2	10	3	2	1	3	2	11	1	1	3	3	1	9
9	Caterin Lizeth Jimenez	2	1	3	2	3	11	3	3	1	3	2	12	3	3	3	3	3	15
10	Karen Johana Gustin	1	3	3	3	2	12	2	1	2	3	3	11	1	2	3	1	3	10
11	Juan Felipe Perafan	1	1	1	1	3	7	3	3	1	3	3	13	1	2	2	3	1	9
12	Laura Isabel Munoz	3	3	2	2	3	13	2	3	1	3	3	12	2	1	2	1	3	9
13	Breyden Alexander Enciso	2	2	2	2	1	9	3	3	1	3	1	11	1	2	3	1	3	10
14	Kiara Isabel Hoyos	2	2	3	2	2	11	3	3	1	3	2	12	2	2	3	1	2	10
15	Sergio Alejandro Munoz	2	2	2	2	3	11	1	2	1	3	3	10	2	1	1	2	1	7
16	Ana Isabel Diago	3	3	3	3	3	15	3	3	1	3	1	11	3	3	3	2	1	12
17	Karol Valentina Villano	2	2	2	3	1	10	2	2	1	3	2	10	1	2	3	1	1	8
18	Ana Sofia Burbano	1	2	3	3	3	12	2	3	3	3	3	14	3	3	3	3	2	14
19	Angela Maria Chamorro	1	1	2	3	2	9	1	3	1	3	2	10	2	1	3	1	1	8
20	Johan Camilo Quinayas	1	3	3	1	3	11	2	1	1	3	1	8	1	2	3	2	1	9
21	Angel Camilo Cajiao	1	2	1	1	3	8	2	1	1	3	2	9	3	2	2	1	2	10
22	Juan Daniel Bedoya Paez	1	1	2	1	2	7	1	3	1	2	2	9	1	2	1	1	1	6
23	Brayan Estiven Manquillo	3	1	2	1	1	8	1	3	1	3	3	11	3	3	3	1	1	11
24	Juan Sebastian Tunubala	2	3	2	2	2	11	2	2	1	3	2	10	3	3	1	1	1	9
25	Eileen Daniela Cruz	1	2	2	1	3	9	2	3	1	2	3	11	3	1	3	1	3	11
26	Isabel Sofia Perez	2	2	3	2	2	11	2	3	1	3	3	12	1	3	2	2	1	9
27	Cristian Arturo Burbano	1	3	3	2	3	12	2	3	1	3	2	11	1	2	3	3	3	12
28	Isabel Sofia Jaramillo	2	3	3	3	1	12	1	2	3	3	3	12	3	3	3	1	3	13
29	Sebastian Camilo Nieves	2	2	3	2	3	12	2	3	1	3	3	12	1	2	3	2	2	10
30	Cristian David Llanos	3	2	3	3	3	14	2	2	1	3	3	11	1	3	2	2	1	9
31	Laura Sofia Gomez	1	1	2	3	3	10	2	3	1	3	3	12	1	1	1	2	2	7
32	Helen Sofia Molina	1	2	3	3	2	11	2	3	2	3	2	12	3	2	2	1	2	10
33	Sonia Cely	3	3	2	2	3	13	2	3	1	3	2	11	1	2	3	1	2	9
34	Natalia Jimenez Munoz	3	3	1	2	2	11	2	3	1	3	1	10	2	3	3	1	1	10
35	Angie Vanessa Estrada	1	1	3	2	2	9	2	3	3	3	2	13	2	3	3	1	2	11
36	Eduar Alexi Ortega	3	3	3	3	2	14	3	3	2	3	2	13	3	3	3	2	3	14
37	Laura Martinez Duenas	1	2	1	2	2	8	3	3	1	3	1	11	1	2	1	1	1	6
38	Cristian Guillermo Palma	1	3	2	2	2	10	3	3	1	3	3	13	2	2	3	1	2	10
39	Diana Sofia Urbano	1	3	3	2	3	12	2	3	1	3	2	11	1	2	3	1	1	8
40	Dayana Isabella Velasco	1	2	1	2	3	9	3	3	2	3	1	12	1	1	1	3	1	7
41	Samuel Felipe Medina	3	3	3	3	3	15	3	2	2	3	3	13	2	3	3	1	3	12
42	Sarita Estefanya Cabrera	2	3	3	1	3	12	2	3	2	3	3	13	1	3	3	2	3	12
43	Daniel Fernando Gurrute	2	2	1	2	2	9	2	3	1	3	3	12	1	2	2	2	3	10
Total							220						206						84
							18						18						7

Figure S2: Data and assessment system on students' instructional sensory preferences

Representative Examples

Figure S3: An example of screenshots of the nomenclature representative examples on the Genially platform

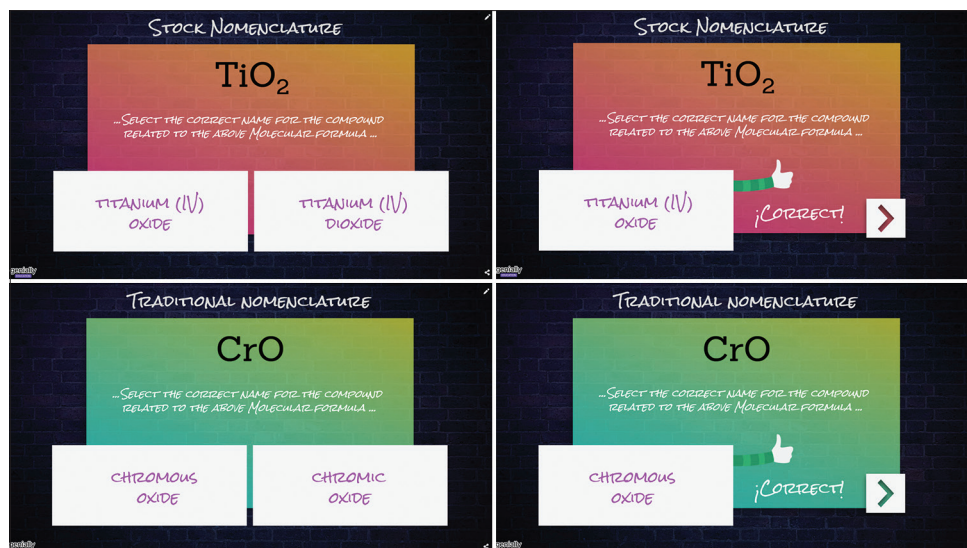


Figure S4: An example of screenshots of the nomenclature representative exercises on the Genially platform

TEST FOR THE EVALUATION OF THE LEARNING OBJECTIVE WITH THE FLIPPED CLASSROOM METHODOLOGY

Date: (dd/mm/yy): ___/___/___ Program: _____

Dear Student:

You have participated in a ludic session using a flipped classroom methodology to learn the nomenclature of inorganic compounds. This evaluation will help us establish trends to determine whether the learning objectives were fully met as intended at the beginning of the proposal. Please assist us by answering the quiz as objectively as possible.

1. Oxides are typically formed by the combination of:

A. Oxygen with metals and non-metals

B. Metals and non-metals

C. Any element with metals and nonmetals

2. Determine the correct formula for the compound named Chromium (III) oxide using Stock Nomenclature.

A. CrO

B. Cr₂O₃

C. Cr₃O₂

3. In systematic nomenclature, the correct name for the compound N₂O₃ is:

A. Dinitrogen trioxide

B. Nitrogen trioxide

C. Trinitrogen dioxide

4. Oxides are binary compounds resulting from the reaction of:

A. Metallic and non-metallic elements with any element

B. Metallic and non-metallic elements with oxygen in any oxidation state

C. Metallic and Non-Metallic Elements with oxygen having oxidation state -2

5. The compound NaOH is classified as:

A. Oxoacids

B. Oxides

C. Bases

6. The correct name for Fe₂O₃ is:

A. Ferric oxide

B. Ferric acid

C. Iron (I) oxide

7. In systematic nomenclature, CH₄ is referred to as:

A. Carbide tetrahydride

B. Carbon tetrahydride

C. Carbide hydride

8. In traditional nomenclature, HCl (aq) is referred to as:

A. Chlorine hydride

B. Hypochlorous acid

C. Hydrochloric acid

9. Which of the following compounds is classified as a basic oxide, considering the types of oxides that can be formed?

A. NO₂

B. CO

C. MgO

10. The correct formula for copper (II) nitrite is:

A. Cu (NO₃)₂

B. CuNO₃

C. CuNO

Figure S5: Test to evaluate learning objectives with multiple choice questions with only one answer

Quizizz interface showing a quiz report for 'Nomenclatura Inorganica'. The report displays a grid of student performance across 10 questions (Q2-Q10). The columns represent questions and the rows represent individual participants. Green cells indicate correct answers, and red cells with an 'x' indicate incorrect answers. The 'Points Out of 10' column shows the score for each participant.

Participant	Score	Points Out of 10	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Nayibe Cuaran	8030	10 (100%)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Jelson Palacios	7650	9 (90%)	✓	✓	✓	✓	✓	✓	✓	✗	✓
luis Paz	6200	8 (80%)	✗	✓	✓	✓	✓	✓	✓	✓	✗
Favian Mamian	5410	8 (80%)	✗	✓	✗	✓	✓	✓	✓	✓	✓
Sofia	5400	7 (70%)	✗	✗	✗	✓	✓	✓	✓	✓	✓
Valentina Muñoz	5950	7 (70%)	✗	✓	✓	✗	✓	✓	✓	✓	✗
Isabella Manzano	5030	7 (70%)	✓	✓	✓	✗	✓	✓	✓	✗	✓
Karenmanquillo	6190	7 (70%)	✓	✗	✗	✗	✓	✓	✓	✓	✓
Goku	5890	7 (70%)	✗	✗	✓	✓	✓	✓	✓	✗	✓
Joaquin Ignacio Cometa ...	4150	6 (60%)	✗	✓	✗	✓	✓	✓	✓	✓	✗
J beca	4760	6 (60%)	✗	✓	✓	✓	✓	✗	✓	✗	✗
Lauraipia	4750	6 (60%)	✗	✓	✗	✗	✓	✓	✓	✗	✓

Figure S6: Quizizz platform screenshot where evaluative test was taken

SATISFACTION SURVEY OF EXPERIENCE WITH THE EDUCATIONAL TOOLS AND THE FLIPPED CLASSROOM APPROACH

Date: (dd/mm/yy): ____ / ____ / ____ Program: _____

Dear Student:

You have participated in a ludic session using a flipped classroom methodology to learn the nomenclature of inorganic compounds. Your opinion will help us improve the activity. Please, help us fill out this survey in the sincerest way. These are the following scales: 1. Not agree. 2. Partially agree. 3. Agree.

Graphical interface and functionality**Questions/response****1 2 3**

- Q1. The graphic design and work environment always turned out to be pleasant
 Q2. The instructions for exploring the educational platform were clear and precise
 Q3. The buttons and hyperlinks on the platform functioned properly
 Q4. The language used was easy to understand for interacting with the educational platform
 Q5. The educational platform provided enabled the deployment of functions to meet their expectations

Content relevance**Questions/Response****1 2 3**

- Q6. The presentation order of each section facilitates learning inorganic nomenclature
 Q7. Each hyperlink should display relevant and easily readable information: text, graphics, and rules
 Q8. The examples provided in the sections are clear and helpful in reinforcing learning
 Q9. The exercises presented in each challenge have been relevant for facilitating your learning process
 Q10. The tools used for playful learning strategies provide high-quality content presentation

Student's perception**Questions/Response****1 2 3**

- Q11. It was motivating to use the educational tools supported by the Genially platform
 Q12. Values interactive tools with a high level of satisfaction to enhance their learning experience
 Q13. Playful tools have been crucial in achieving learning goals in naming inorganic compounds
 Q14. I would recommend this educational platform to other students as a valuable learning tool
 Q15. I would use the educational platform again as a learning tool

Figure S7: Questions proposed for activity validation format