Critical and Creative Thinking in Elementary Science Classes: Assessment for Learning[1]

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Abstract

Life contexts, today, strongly marked by uncertainty, justify a science education that helps individuals to deal effectively and productively with socially relevant issues involving science and technology. This requires an emphasis on the development of Critical and Creative Thinking (CCT), as they are fundamental to achieving maximum effectiveness in decision-making and problem-solving, within a framework of personal fulfillment and sustainable development. The concern with explicitly and foundationally developing students' CCT potential should be accompanied by an assessment for learning that also integrates and considers the mobilization of thinking skills involved in critical and creative thinking. This implies, deliberately and explicitly, articulating frameworks that support congruent actions in terms of promoting and assessing student learning while integrating CCT. Additionally, assessment for learning should be associated with the diversification of activities and instruments and quality feedback mechanisms that encourage improvement. From this perspective, feedback can (and should) also foster awareness and collaboration and active student involvement in the (self)regulation of their learning processes. In this framework, associated with the diversification of assessment instruments and activities for learning, in conjunction with the implementation of feedback mechanisms for improvement and the development of science learning and competence areas involving CCT, the use of technologies and digital tools, as proposed in the European Framework for Digital Competence for Educators, is noteworthy to enhance learning and assessment for learning. This presentation outlines theoretical frameworks and focuses on excerpts of science activities, oriented towards CCT, integrating assessment for learning.

Keywords: *Critical and Creative Thinking, Science education, Assessment for learning, Feedback, Digital tools*

1. Introduction

The relevance of critical and creative thinking (CCT) has been advocated by various organizations, educators, and researchers, and it has been embedded in multiple documents, including curricular guidelines. In recent decades, the emphasis on curricula in different countries has evolved and shifted to include new areas and reinforce types of thinking and skills of pressing relevance today. This shift reflects the recognition of what children and young people need to learn to face a future marked by complexity and unpredictability. They will encounter professions that have not yet been created, use technologies that have not yet been invented, and face social challenges that are still impossible to anticipate.

In Portugal, the promotion of students' Critical and Creative Thinking (CCT) throughout their educational journey has been explicitly mentioned in curricular guidelines. An example is the transversal document "Profile of Students Leaving Compulsory Education" (PASEO) [1]. This document outlines ten areas of competence that all students should develop. One of these areas of competence concerns "Critical and Creative Thinking," which implies that students, by the end of compulsory education, should be able to: (i) think comprehensively and in-depth, observing and analyzing information, experiences, or ideas, arguing using implicit or explicit criteria, aiming for a well-

[1] This work is financially supported by National Funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the projects (https://doi.org/10.54499/UIDB/00194/2020) and UIDP/00194/2020 (https://doi.org/10.54499/UIDP/00194/2020))

founded position; (ii) integrate different types of knowledge, both scientific and humanistic, using various methodologies and tools to think critically; (iii) anticipate and evaluate the impact of their decisions; and (iv) develop ideas and solutions in an imaginative and innovative way, resulting from interaction with others and/or personal reflection, applying them to different contexts and areas of learning [1].

Consistently, the curricular document "Essential Learnings" [2] for the subject of natural sciences in basic education (5th to 9th grade – students aged between 10 and 14 years) emphasizes the contribution of teaching natural sciences, contextualized in real and current situations from which guiding problem-questions for learning can emerge. This approach aims to develop PASEO areas of competence, particularly "Critical and Creative Thinking", "Scientific, Technical, and Technological Knowledge", "Reasoning and Problem Solving" and "Well-being, Health, and Environment." The "Essential Learnings" (AE) document acknowledges the focus on developing students' CCT in the statement of transversal learnings such as: (i) Formulating and communicating critical and scientifically related opinions about Science, Technology, Society, and Environment (CTSA) and (ii) Developing a constructive critical attitude that leads to the improvement of living conditions and individual and collective health. Consistently, examples of specific Essential Learnings that refer to CCT include: (i) Arguing about the impacts of human activities on air quality and measures that contribute to its preservation, and (ii) Formulating critical opinions on human actions that affect biodiversity and the importance of its preservation. In this document, there is an explicit reference to CCT in the "Strategic teaching actions oriented towards PASEO," particularly in the statement "Promote strategies that develop students' critical and analytical thinking, focusing on: mobilizing argumentative discourse (oral and written) (expressing a position, thinking and presenting arguments and counterarguments, rebutting counterarguments); organizing debates that require the support of assertions, the elaboration of opinions, or the analysis of facts or data (p. 8) [1].

The concern with explicitly and substantively developing students' CCT potential should be concomitant with an assessment for learning that also integrates and encompasses the mobilization of thinking skills involved in critical and creative thinking. Assessment for learning should be associated with the diversification of activities and tools and quality feedback mechanisms that encourage improvement.

From this perspective, feedback can (and should) also foster awareness, collaboration, and the active involvement of students in the (self-)regulation of their learning processes. This implies the explicit and continuous operationalization of opportunities for self-assessment, peer assessment, and peer evaluation, based on social interaction and shared and negotiated feedback between students and teachers [3] and [4].

In this framework, associated with the diversification of tools and assessment activities for learning, in conjunction with the operationalization of feedback mechanisms for the improvement and development of science learning and areas of competence involving CCT, the use of digital technologies and tools is relevant.

In this field, and combined with the concern about promoting CCT in education in general and science education in particular, it is worth mentioning, as an example, digital tools that support strategic planning, organization, presentation, and communication (such as Canvas), argumentation and counter argumentation (such as Kialo-edu), as well as tools that enable the provision of immediate or real-time feedback (which include forms questionnaires, Quizizz, Kahoot, and Formative) [5].

In this communication, illustrative examples of the science teaching and learning process oriented towards CCT are presented, integrating assessment for learning, with a focus on feedback mechanisms, including the use of digital tools.

2. Critical and Creative Thinking: Theoretical Frame

Following the research work developed [6], [7] and [8], in an integrative vision, Critical and Creative Thinking (PCC) is ethical and effective thinking in various contexts and domains to produce and evaluate creative products, solve problems, and make decisions about what to believe or how to act responsibly and sustainably. In operational terms, the PCC involves different abilities, dispositions or attitudes/values, criteria/standards, and knowledge, as systematized in the table below.

Frame 1: Identification of the four elements of the PCC to be considered in the development of didactic proposals for science teaching.

Abilities	Dispositions/attitudes/values	Criteria/standards	Knowledge
Basic Clarification: Summarize, identify, or formulate reasons, conclusions, or arguments. Basic Support: Evaluate the credibility of sources and observations. Elaborate Clarification: Define operationally and classify. Inferences: Make inductions and evaluate value judgments. Strategies and Tactics: Decide and interact with others, for example, to present a position to a particular audience. Creativity: Exhibit originality, flexibility, and elaboration.	Be open-minded. Look for and acknowledge reasons publicly. Utilize and cite credible sources and be well-informed. Consider and seek alternatives. Be sensitive to others' feelings, knowledge levels, and elaboration. Value collaboration, integrity, and intellectual satisfaction. Respect evidence. Show perseverance, resilience, and fearlessness of error. Uphold values like justice, life, truth, and honesty.	Clarity and Rigor Precision considering the overall situation. Metacognition Consistency and Coherence Systematicity Intellectual Independence Prudence and Inquiry Impartiality Planning and Strategy	Scientific and Technological Theories and Explanations History of Science and Technology (S&T) Nature of Science and the Scientific Method (PCC) Major Ideas and Concepts in S&T Current Research Fields and Contexts in S&T

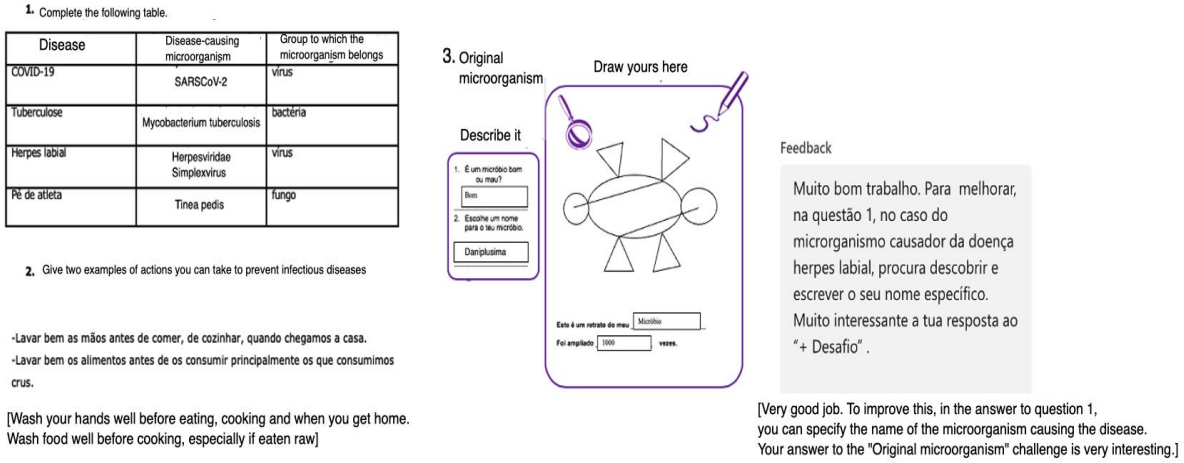
Source: adapted from [6]

The above framework serves as a guiding reference for the design and construction of didactic proposals to ensure they (i) have an explicit focus on the Nature of Science (PCC), by coherently integrating learning activities that are operationalized through the development of items, prompts, or inciting questions related to PCC and (ii) integrate teaching strategies aimed at enhancing students' engagement with PCC during learning activities.
From this perspective, and according to the same authors, the guidelines designed to enhance opportunities for the intricate mobilization of knowledge, abilities, criteria/ standards, and dispositions or attitudes/values of PCC within the context of implementing these didactic proposals are: (i) Create and sustain a learning environment that encourages students to articulate their thoughts, test ideas or proposals, and confront their ideas with those of others; (ii) Give students time to think and experiment independently; (iii) Create multiple opportunities for brainstorming and generating ideas (many ideas, unconventional ones, and in different categories), elaborating on ideas, and developing an original product; (iv) Actively engage students in communicating positions/opinions and arguing about societal problems and issues, including controversial socio-scientific questions; foster debate and discussion based on productive questions such as: "What reasons support the conclusion that [...]?", "Can you elaborate a bit more on the reasons for reaching that conclusion?" and "Are these reasons acceptable? Why?"; (v) Manage the participation and support provided to students to ensure their success, without stifling their originality, fluidity, and primary responsibility for seeking a solution or answer. [2]

3. Science Teaching and Learning with PCC Orientation: Assessment for Learning Associated with Feedback Mechanisms

The presented example integrates activities aimed at developing areas of competence, particularly related to CCT, in conjunction with achieving essential learnings on the topic "Microorganisms," as outlined in Portuguese curricular guidelines for teaching physical and natural sciences in elementary education (students aged 10-12). Within this framework, a sequence of activities involved researching and organizing information on the classification and grouping of microorganisms, specifying classification criteria, and describing and drawing a "microorganism." The activity completed by the students, submitted via a digital platform, allowed for the provision of feedback focused on the created product, with suggestions for improvement.
The following examples illustrate the students' work and the feedback provided.

Figure 1: Student A's Production – Classification of microorganisms, description, and drawing of an "original" microorganism.



1. Complete the following table.

Disease	Disease-causing microorganism	Group to which the microorganism belongs
COVID-19	SARSCoV-2	vírus
Tuberculose	Mycobacterium tuberculosis	bactéria
Herpes labial	Herpesviridae Simplexvirus	vírus
Pé de atleta	Tinea pedis	fungo

2. Give two examples of actions you can take to prevent infectious diseases

-Lavar bem as mãos antes de comer, de cozinhar, quando chegamos a casa.
-Lavar bem os alimentos antes de os consumir principalmente os que consumimos crus.

[Wash your hands well before eating, cooking and when you get home.
Wash food well before cooking, especially if eaten raw]

3. Original microorganism

Draw yours here

Describe it

1. É um micróbio bom ou mau? Bom
2. Escolhe um nome para o teu micróbio. Daniplusima

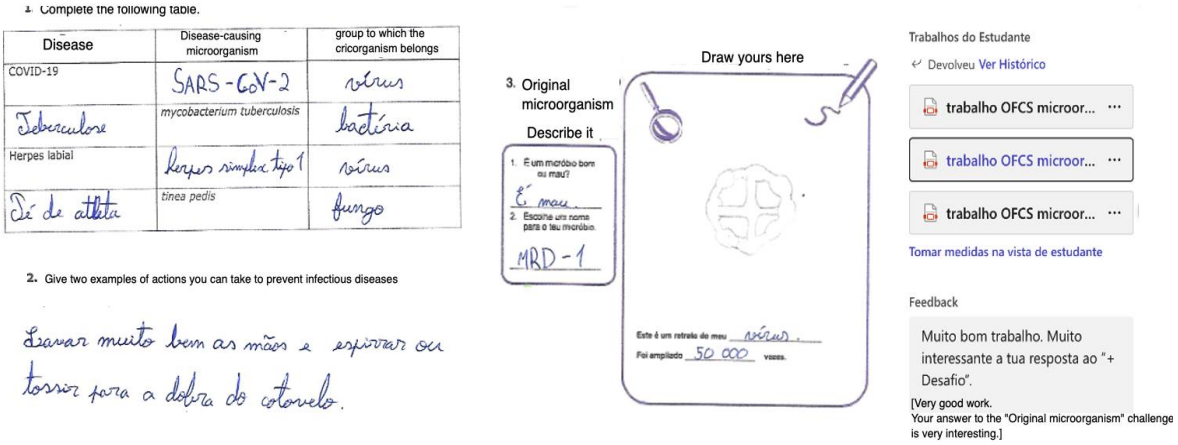
Este é um retrato do meu Micróbio
Foi ampliado 1000 vezes.

Feedback

Muito bom trabalho. Para melhorar, na questão 1, no caso do microrganismo causador da doença herpes labial, procura descobrir e escrever o seu nome específico. Muito interessante a tua resposta ao "+ Desafio".

[Very good job. To improve this, in the answer to question 1, you can specify the name of the microorganism causing the disease. Your answer to the "Original microorganism" challenge is very interesting.]

Figure 2: Student B's Production – Classification of microorganisms, description, and drawing of an "original" microorganism.



1. Complete the following table.

Disease	Disease-causing microorganism	group to which the cricorganism belongs
COVID-19	SARS-CoV-2	vírus
Tuberculose	*mycobacterium tuberculosis*	bactéria
Herpes labial	Herpes simplex tipo 1	vírus
Pé de atleta	*tinea pedis*	fungo

2. Give two examples of actions you can take to prevent infectious diseases

Lavar muito bem as mãos e espirrar ou tossir para a dobra do cotovelo.

3. Original microorganism

Draw yours here

Describe it

1. É um micróbio bom ou mau? É mau.
2. Escolhe um nome para o teu micróbio. MRD-1

Este é um retrato do meu vírus.
Foi ampliado 50 000 vezes.

Trabalhos do Estudante

Devolveu Ver Histórico

trabalho OFCS microor...
trabalho OFCS microor...
trabalho OFCS microor...

Tomar medidas na vista de estudante

Feedback

Muito bom trabalho. Muito interessante a tua resposta ao "+ Desafio".

[Very good work.
Your answer to the "Original microorganism" challenge is very interesting.]

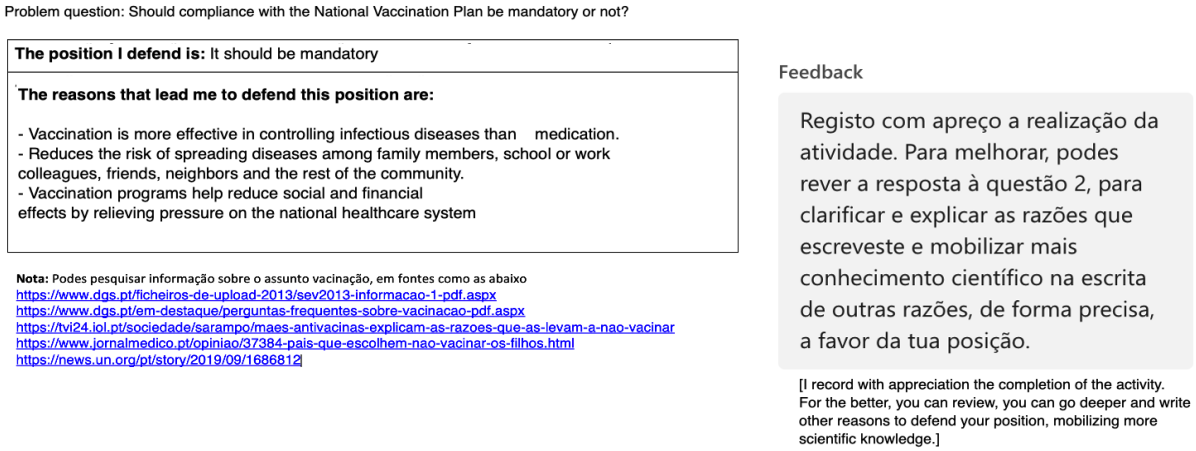
The analysis of the students' work demonstrates the mobilization of scientific knowledge and CCT skills concerning microorganisms, both beneficial and pathogenic, as well as examples of actions to prevent infectious diseases. Within the scope of the learning sequence, other activities oriented towards CCT involved the production of argumentative text. Alongside the guideline referring to the position article, students were also provided with the rubric to be used for evaluating the argumentative essay, as illustrated below.

Figure 3: Rubric for evaluating the production of argumentative essay.

Learning goal: Discuss the importance of vaccines	Performance Domain: Writing Performance descriptor: mobilizes skills, knowledge, and scientific language in the production of argumentative text			
Criteria	Performance level			
	insufficient	Enough	Good	Very good
Structuring (follows the guidelines)	Does not respect the guidelines provided.	Follow only some of the guidelines provided.	Respects the main guidelines provided.	Comply with all the guidelines provided.
Scientific information, its relevance and correctness	mobilizes insufficient and/or inconsistent scientific knowledge and addresses the issue sideways or superficially	mobilizes some relevant scientific knowledge and addresses the issue with some deviations and/or inconsistencies	mobilizes a lot of relevant scientific knowledge and addresses the issue globally	mobilizes relevant scientific knowledge and addresses the issue without deviation
Clarity and discursive cohesion	Produces speech, generally inconsistent and sometimes unintelligible, without defining a concrete point of view	Produces a globally coherent speech, despite some ambiguities	Produces a coherent speech with few ambiguities	Produces a coherent speech without ambiguities, clearly defining your point of view
PCC	Does not mobilize or mobilizes PCC capabilities with limited effectiveness (presents work without originality and without explaining personal points of view,...).	Mobilizes PCC capabilities with some effectiveness (shows some inconsistency in argumentation,...).	Mobilizes PCC with considerable effectiveness (shows little inconsistency in argumentation,...).	Mobilizes PCC with a high degree of effectiveness (presenting original work and analyzes and/or presents ideas, decisions, solutions,... arguing based on rational reasons).

This allowed students to familiarize themselves with the criteria focused on in the evaluation and guided the feedback provided to them, indicating their performance level. This was combined with descriptive feedback inserted into the platform when returning the work to the students.
The following examples demonstrate the production of argumentative texts and the associated feedback.

Figure 4: Student C's Production – Argumentative essay based on the question "Should compliance with the National Vaccination Plan be mandatory or not?"



Problem question: Should compliance with the National Vaccination Plan be mandatory or not?

The position I defend is: It should be mandatory

The reasons that lead me to defend this position are:

- Vaccination is more effective in controlling infectious diseases than medication.
- Reduces the risk of spreading diseases among family members, school or work colleagues, friends, neighbors and the rest of the community.
- Vaccination programs help reduce social and financial effects by relieving pressure on the national healthcare system

Nota: Podes pesquisar informação sobre o assunto vacinação, em fontes como as abaixo
https://www.dgs.pt/ficheiros-de-upload-2013/sev2013-informacao-1-pdf.aspx
https://www.dgs.pt/em-destaque/perguntas-frequentes-sobre-vacinacao-pdf.aspx
https://tvi24.iol.pt/sociedade/sarampo/maes-antivacinas-explicam-as-razoes-que-as-levam-a-nao-vacinar
https://www.jornalmedico.pt/opiniao/37384-pais-que-escolhem-nao-vacinar-os-filhos.html
https://news.un.org/pt/story/2019/09/1686812

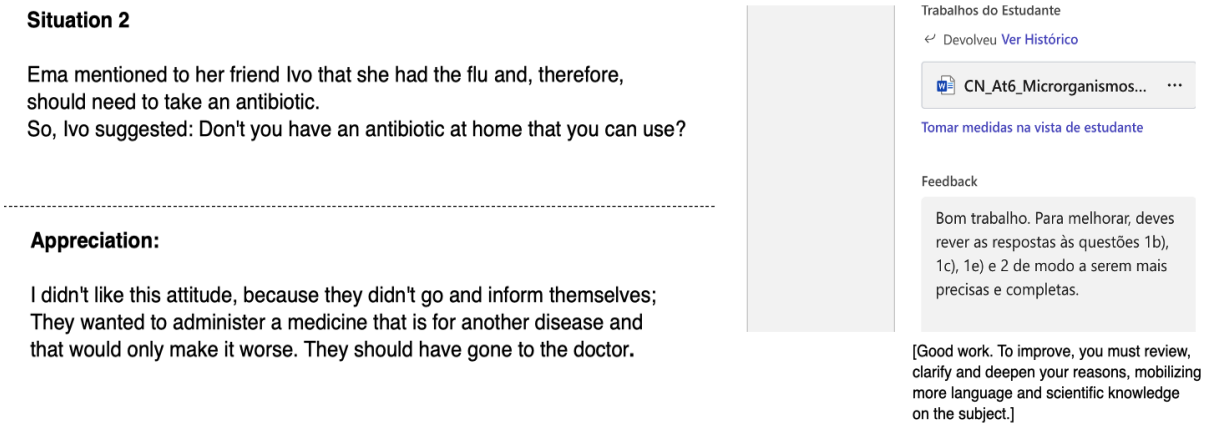
Feedback

Registo com apreço a realização da atividade. Para melhorar, podes rever a resposta à questão 2, para clarificar e explicar as razões que escreveste e mobilizar mais conhecimento científico na escrita de outras razões, de forma precisa, a favor da tua posição.

[I record with appreciation the completion of the activity. For the better, you can review, you can go deeper and write other reasons to defend your position, mobilizing more scientific knowledge.]

Another activity, also focused on PCC requests the evaluation of "cases" corresponding to situations that could be experienced in daily life regarding the use of medications in treating infectious diseases. The following examples illustrate the students' work and the teacher's feedback.

Figure 5: Student D's Production – Case Analysis on the use of antibiotics and over-the-counter medications



Situation 2

Ema mentioned to her friend Ivo that she had the flu and, therefore, should need to take an antibiotic.
So, Ivo suggested: Don't you have an antibiotic at home that you can use?

Appreciation:

I didn't like this attitude, because they didn't go and inform themselves; They wanted to administer a medicine that is for another disease and that would only make it worse. They should have gone to the doctor.

Trabalhos do Estudante

Devolveu Ver Histórico

CN_At6_Microrganismos...

Tomar medidas na vista de estudante

Feedback

Bom trabalho. Para melhorar, deves rever as respostas às questões 1b), 1c), 1e) e 2 de modo a serem mais precisas e completas.

[Good work. To improve, you must review, clarify and deepen your reasons, mobilizing more language and scientific knowledge on the subject.]

Figure 6: Student E's Production – Case Analysis on the use of antibiotics and over-the-counter medications

Situation 2

Ema mentioned to her friend Ivo that she had the flu and, therefore, should need to take an antibiotic.
So, Ivo suggested: Don't you have an antibiotic at home that you can use?

Appreciation:

- Antibiotics cannot fight viruses.
- You should not use old medicines or those from other people, as they may be spoiled.
- Antibiotics are not used without a prescription, because doctors know which ones are best for us.
- A medicine for otitis would never solve the flu because the pathogenic microorganism is not the same.

Trabalhos do Estudante
Devolveu Ver Histórico
CN_At6_Microrganismos...
Tomar medidas na vista de estudante

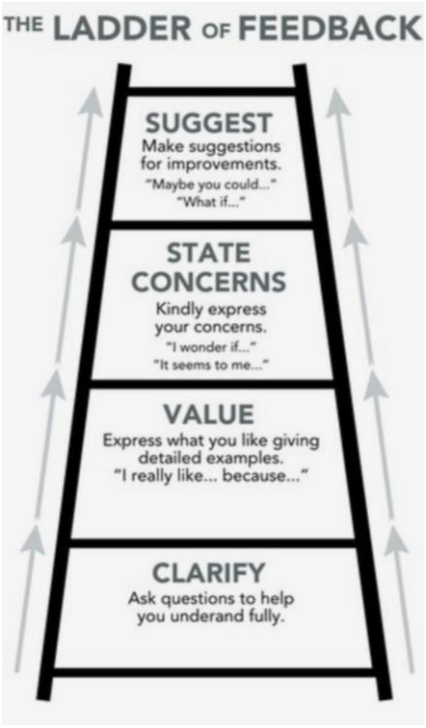
Feedback

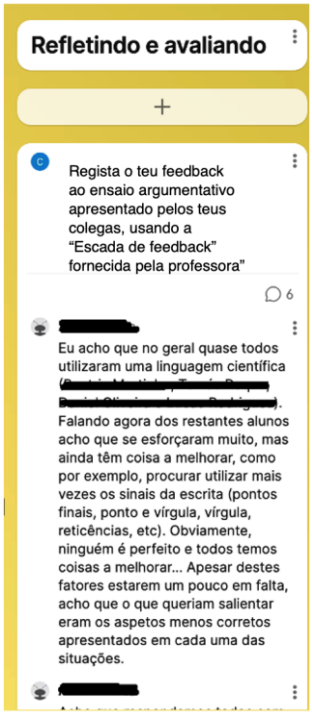
Bastante bom trabalho. Para melhorar, podes organizar o discurso de argumentação, de modo a clarificar e a aprofundar as razões que suportam a tua apreciação.

Very good job. To improve, you can reorganize the argument essay in a more cohesive way, clarifying and deepening the reasons that support your position.]

Following the sharing of the case evaluations using “Padlet,” each student had the opportunity to conduct a "peer assessment."

Figure 7: Feedback Ladder and student productions in the context of peer assessment





[Reflecting and evaluating]

[Record your feedback on the argumentative essay presented by your classmates, using the feedback ladder provided by the teacher]

[I think that in general everyone used scientific language.

I think they made a lot of effort, but there are still things to improve, such as using writing signs more often. We all have things to improve. Although these aspects are a little lacking, I think what they wanted to highlight were the aspects that were less correct in the situation.]

Lastly, the use of digital tools from an assessment-for-learning perspective is noteworthy, as they allow for the distribution of real-time or immediate feedback in the case of closed-response questions. Using Microsoft Forms, students were also involved in self-assessment of their learning, reflection on the feedback received, and evaluation of the activities they performed.
From the analysis of student responses, it is evident that they appreciated using digital tools and engaging in the activities. They expressed the view that these tools promoted their interest in learning science and enabled them to achieve learning outcomes and develop PCC-related competencies. The analysis of data collected through observation and documentary analysis of students' written productions in the context of various PCC-focused activities also indicates the achievement of essential learning and the development of PCC abilities among the students involved.

4. Final considerations

In the context of contemporary societies, strongly characterized by rapid technological and social changes, science education should aim to develop competencies, including those that encompass critical and creative thinking (PCC). In this framework, the presented examples, as excerpts of didactic-pedagogical science practices oriented towards PCC, grounded, and based on the outlined references, demonstrate pathways capable of enhancing the achievement of this goal.
The activities initiated and sustained student engagement, which they found motivating, challenging, and productive, driving them to seek information and mobilize skills such as communication, decision-making, and argumentation. The use of digital tools in the teaching and learning process, incorporating assessment for learning, enhanced active student involvement and enabled the timely distribution of quality feedback, supporting the revision of completed work and, consequently, the improvement of learning and the development of PCC.

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