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ORIGINAL ARTICLE

Art and science: Possibilities of teaching for creativity

Arte e Ciência: possibilidades de um ensino para a criatividade

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Abstract: This paper aims to present the structure of a short course developed to promote teaching for creativity based on the interdisciplinarity between Art and Science. In addition, it seeks to reflect on the contributions that this type of teaching can provide for the initial teacher education of Chemistry and Visual Arts students. Throughout the short course, the influence on the development and expression of creativity of both the individual, the group and the environment in which the students are in is evident. Still, the interdisciplinarity explored within teaching for creativity contributed to the promotion of complex thinking, in which several dimensions of knowledge could be articulated.

Keywords: chemistry teaching; interdisciplinarity; developing creativity; teacher education; art and science.

Resumo: O objetivo deste trabalho é apresentar a estrutura de um minicurso desenvolvido no intuito de promover um ensino para a criatividade a partir da interdisciplinaridade entre Arte e Ciência. Além disso, busca refletir sobre as contribuições que este tipo de ensino pode proporcionar para a formação inicial de licenciandos em Química e Artes Visuais. Ao longo do minicurso, fica evidente a influência tanto do indivíduo quanto do grupo e do ambiente no qual os alunos estão inseridos para o desenvolvimento e a expressão da criatividade. Ainda, a interdisciplinaridade explorada dentro de um ensino para a criatividade contribuiu para a promoção de um pensamento complexo, no qual diversas dimensões do conhecimento puderam ser trabalhadas.

Palavras-chave: ensino de química; interdisciplinaridade; desenvolvimento da criatividade; formação de professores; arte e ciência.

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Introduction and theorical framework

Art and Science are two fields of knowledge that are often placed on opposite sides. This dichotomy has been reinforced mainly through the positivist worldview that has been constructed over time and is still present today. However, when we look at the History of Science and the History of Art, we notice that both have a very close relationship, playing a central role in significant milestones in world history, such as: the relationship between the Renaissance period and the Scientific Revolution (Leonardo da Vinci and his anatomical studies); astronomy and the visual representation of Galileo Galilei, who also had artistic training; Impressionism and optical studies; and also the relationship between art and technology in the 20th century with Futurism, or more recently, the connection between Science, Art, and Artificial Intelligence, which continue to challenge the limits of human creativity (Braga; Guerra; Reis, 2008; Farthing, 2011; Gombrich, 1999; Leite, 2024). According to Bronowski (1977) and Caruso (2021), major transformations in the way we understand the world occurred when Art and Science walked together, exerting great influence and also being influenced by the entire historical-social context.

In this sense, it is possible to affirm that both Science and Art are fields of knowledge present in all cultures. As Bronowski (1983) states, there is no single culture dedicated solely to science or only to Art. This may be related to the fact that both develop through imagination and are governed by the same complex human brain, that is, the same person who is capable of doing Science is also capable of creating Art (Zamboni, 2006).

Although they have distinct characteristics that differentiate them in various aspects, such as the objectives of their activities (Kuhn, 1982), this study, following Bachelard (1974), adopts the notion that both should be understood as complementary. It is through this complementary look that we can achieve a better understanding of the complexity of human beings and nature, especially from the Contemporary Age, which extends to the present day, and increasingly demands the development of a new scientific spirit. This spirit moves towards overcoming dichotomies, it views knowledge as a process under construction, and emphasizes the importance of the dialectic between subject, object, theory, and practice.

From this complementary perspective, this study explores creativity and imagination as main aspects that relate to artistic and scientific activity. This ability to predict, that is, to place oneself in imaginary situations and thereby plan and change one's actions before putting them into practice, allows human beings to consider different possibilities and ponder them in order to better achieve the desired outcome (Bronowski, 1983).

In this sense, according to Bronowski (1983), imagination would be the human capacity to construct images in the mind and to rework them, since it can store images of absent things, which do not present themselves to the senses, thus allowing man to go beyond the limits of immediate experience.

Furthermore, according to Vygotsky (2009), there are two types of human activities: reproductive, which is related to memory and seeks to reconstruct past experiences; and creative, which is more deeply related to the imagination, and, from this, it projects experiences not yet lived, which makes it an activity that allows man to think about the future. In this sense, imagination is the basis of creativity.

Scientific and artistic activities, through imagination and creativity, seek to find and, in a certain way, create an order or unity in the variety of aspects of nature that are presented to us. Such activities explore hidden similarities, try to merge them, and that is where the creative act lies. It is from this movement that original thoughts or creations

develop, and they do not end there, but go to an audience that recreates them for themselves. The product of creativity exists in two moments: in the act of making it, and in the moment of appreciation. In the second moment, we have the opportunity to experience and recreate it for ourselves, making it meaningful (Bronowski, 1979).

Both imagination and creativity are human abilities that have allowed humankind's survival and freedom since the beginning of its evolutionary process. This freedom is related to the exploration of nature, not its denial. Such capabilities allowed man to retain the image of the animal in their minds even when it was not present and to become used to its idea and behavior, in order to take actions beyond instinctive ones. In this sense, both the spear and the cave paintings created are examples of activities that demonstrate that man overcomes the mechanical impulses of nature. Therefore, it is possible to affirm that our spirit is creative, and the results of creative and imaginative activity are what makes the path to the construction of knowledge possible to this day (Bronowski, 1983).

The teaching of Arts generally encourages exploration of both creativity and a complex perspective on nature. It allows for an approach that considers multiple dimensions of knowledge involved in its construction process — dimensions (philosophical, contextual, intuitive, etc.) that are often ignored in Science Education (Leite, 2024). The interaction between Art, Science, and Education emerges as a promising pathway toward a broader and more integrated understanding of knowledge. This approach challenges the hierarchical structuring of knowledge, typical of positivism, and emphasizes the importance of creativity as a point of convergence between Science and Art. In fact, creativity, often underestimated in the scientific educational context, is recognized as an essential characteristic of scientific practice (Alencar, 1991; Barbosa; Batista, 2011; Bronowski, 1983; Cachapuz, 2014; Rangel; Rojas, 2014; Zamboni, 2006).

Although there is a growing appreciation for creativity in education, methods that prioritize the reproduction of results and concepts over creation and reflection still tend to dominate (Bachelard, 1974; Vasconcelos; Arroio, 2013). This passive approach can lead to gaps in the understanding and experience of the scientific process, as well as in the comprehension of concepts that require abstraction and transitions between different representational levels. Such gaps may impact on the initial training of teachers and other professionals responsible for dealing with the complexity of knowledge (Alencar, 1990; Vasconcelos; Arroio, 2013).

In the context of Chemistry Education, for instance, particular challenges can be observed, such as the predominance of conceptual and pragmatic teaching, which often fails to stimulate students' active and creative participation. The use of laboratory activities based on *recipe-like* instructions and the neglect of transitions between different dimensions of chemical knowledge exemplify these challenges. The lack of reflection on the construction of chemical concepts and the difficulty in navigating between the macroscopic, submicroscopic, and symbolic levels contribute to the perception of Chemistry — or even Science — as a complex and difficult-to-understand discipline (Johnstone, 2000; Kavalek *et al*., 2015).

Some scholars have reflected on and recognized the potential of education in developing creative capabilities (Alencar, 1991; Alencar, Fleith, 2003, 2004; Kind; Kind, 2007). According to Alencar (1991), this is more common in countries such the United States, which has had groups of researchers pointing to the need to cultivate creative behavior in students since 1950.

However, the same author also states that in countries such as Brazil, Portugal, Argentina and Colombia, there is a mistaken view about creativity and ways to develop it among teachers: the idea that the act of creativity only exists in activities developed by artists or geniuses; that creativity is a gift that only some people are born with; or even the extremist thought that a person is either creative or not, there are no levels or a middle ground.

In addition to these points of view, it is possible to mention other attitudes that end up making teaching for creativity something difficult and inhibiting the expression of students' creative abilities. For example: not encouraging the use of imagination; telling students that there is only one correct solution to a certain problem; not providing enough time to solve it; not encouraging students to take risks; not presenting challenges; not tolerating error; or promoting an environment with many prohibitions and criticism (Alencar 1991; Alencar; Fleith; Pereira, 2017).

Kind and Kind (2007) present a difference between creative teaching and teaching for creativity. Referencing the National Advisory Committee on Creative & Cultural Education, they discuss that a lot is said about creative teaching, which is when teachers use creative methodologies and approaches in order to make the educational process more stimulating and effective. According to these authors, creative teaching goes far beyond a specific context or environment (laboratory, group work, among others), it also relates to practice, mediation and teacher planning.

Teaching for creativity, on the other hand, is not discussed as much. In this case, creativity becomes a learning outcome, an objective to be developed and/or achieved. To achieve this, both teachers and students must understand the important elements necessary for developing and expressing this skill. As the aforementioned authors corroborate, if we want creativity to be more than an adjective, a moment, or a tool, we must work on the *ends* and seek better ways of teaching creativity rather than focusing only on the *means* or what *makes teaching creative*.

As previously stated, to promote teaching for creativity, it is necessary to understand this skill as well as the attitudes that encourage or inhibit its development. According to Alencar and Fleith (2003), until the 1970s, research on creativity mainly focused on the individual, the creative profile, and techniques that helped the expression of creativity. However, in recent decades, researchers have begun to consider social, cultural, and historical factors as influences on creative development. According to Alencar and Fleith (2003, p. 1, own translation), "[…] creative production cannot be attributed exclusively to the skills and personality traits of the creator but is also influenced by elements of the environment in which the creator is embedded. Within this contextual view of creativity, which requires an interdisciplinary and systemic approach to be taught, internal and external aspects to the individual are considered in order to better understand how and why an idea is created. Based on contemporary models of creativity, Zavadil, Tschimmel and Silva (2016) bring together the main factors that relate to creativity at the levels of the individual, the environment and the groups they may participate in.

Regarding the creative individual, the main aspects to be observed are: fluency, which is related to the individual's ability to articulate several ideas/responses to the same subject or problem; flexibility, in order to work with different perspectives; originality, which is the ability to formulate new ideas and atypical solutions; elaboration of ideas, which refers to the improvement, polishing of the idea or the creation; openness to

new experiences and fantasy; dedication; tolerance; questioning; etc. In addition to the individual's personality, other elements are also considered in this individual dimension, such as cognitive and creative skills, each person's knowledge and experience, as well as intrinsic motivation (Alencar, Fleith, 2003; Amábile, 1997; Kneller, 1978; Zavadil; Tschimmel; Silva, 2016).

As for the environment, context is considered an essential factor in encouraging and improving creative potential. Therefore, modifying the context to promote creativity is a way of exercising it. Based on this point of view, three models have been developed: Sternberg's (1988) theory of investment in creativity, Amabile's (1983, 1997) componential model of creativity, and Csikszentmihalyi's (1988) systems perspective (Alencar, Fleith, 2003; Zavadil; Tschimmel; Silva, 2016).

According to Zavadil, Tschimmel and Silva (2016) and Alencar and Fleith (2003), the first model points out six different essential aspects for creative expression when considered in an interactive, correlated way: intelligence, intellectual styles, knowledge, personality, motivation, and environmental context. The second theory, although it explores cognitive, motivational and social factors, emphasizes intrinsic motivation. However, it discusses three main elements necessary for creativity that must be articulated: mastery skills; relevant creative processes; and intrinsic motivation. The third theory explores creativity in social systems, as a result of the creator's interaction with the public and their context. Therefore, creativity results from the intersection of three areas: the individual, which includes both genetic traits and personal experiences; the domain, which refers to culture; and the field, which is the social system. In other words, creativity is a result of "[...] a culture that combines symbolic rules, a person who brings novelty to the symbolic domain, and a field of experts who recognize and validate innovation" (Zavadil; Tschimmel; Silva, 2016, p. 197, own translation).

Finally, Zavadil, Tschimmel and Silva (2016) discuss the model presented by Woodman, Sawyer and Griffin (1993), which addresses creative groups, that is, a systemic set of individuals with different personalities who seek to solve a common challenge. In this theory, the factors that influence the expression of creativity in a group would be the diversity of the team; the size and cohesion of the group; the strategies adopted to solve problems and the communicative processes developed by the group; as well as the influence of context.

All aspects related to the development and expression — or inhibition — of creativity, both in terms of teaching practice and of the individual, the context and the group, highlight the notion that the creative process is complex, and does not depend only on the individual, but it involves several variables. To promote teaching for creativity, it is necessary that both teachers and students know and experience these aspects. And regarding the researcher,

> In order to obtain a broader view of the creativity phenomenon, we must consider the interaction between individual and environmental characteristics, the rapid transformations in society that establish new paradigms and demand more suitable solutions to the emerging challenges, and the impact of creative products on society. It is important to remember that, in order to stimulate creative expression in a variety of settings, including schools, workplaces, and other professional environments, it is necessary to prepare individuals to think and act creatively. Additionally, planning interventions within these contexts is crucial to establish favorable conditions for the development of creativity (Alencar; Fleith, 2003, p. 7, own translation).

In light of the aforementioned points, this research aims to explain the structure of a short course developed based on these theoretical references and to observe and reflect on the presence of the elements of teaching for creativity in it, presenting some contributions to the initial education of Chemistry and Visual Arts teachers that could be perceived at the end of the process.

Designing the short course

This paper is part of qualitative research and seeks to identify the elements of teaching for creativity in a short course and its contributions regarding the initial education of Chemistry and Visual Arts teachers.

The short course was designed based on the theoretical references presented so far, which start from a contextual view of creativity, aiming to develop teaching for creativity. Furthermore, it is guided by the interdisciplinarity of the relationship between Arts and Science.

The Arts-Science relationship is explored due to the fact that creativity is one of the main similarities between these two activities. Although the creative act is at the heart of both areas of knowledge, it is clear that throughout the teaching and learning processes of Natural Sciences, little to no space is given for creativity to be actually developed, even though students must resort to their imagination, abstract thinking and make correlations with the symbolic, macroscopic and submicroscopic dimensions of knowledge (Locatelli; Arroio, 2017).

Therefore, this study is based on the principle that Art and its tenets, considering teaching for creativity, can contribute to the education of Chemistry teachers regarding the access and development of creativity and the improvement of the understanding of nature and the dimensions of their knowledge.

During the pandemic, the short course was held online. The researcher had been observing 13 chemistry and 10 visual arts undergraduates throughout the semester. The students were part of the pedagogical subjects of each course, and the professors agreed to carry out the short course during their classes, which were offered on the same day and time. The short course mixed theoretical and practical classes, addressing the historical relationship between Science, Art and the world; the similarities and differences of teaching between these two areas of knowledge, as well as their possibilities; creativity; the representational dimensions of Chemical knowledge, among other topics.

For the practical part of the short course, the students were divided into mixed groups and had to come up with a plan to try to turn something abstract in Chemistry into something visual based on Art, such as the atom. In addition, they would have to present an interpretation of that plan that would go beyond rational logic, exploring a more human, philosophical, subjective and interdisciplinary line, so that both areas were addressed equally throughout the process. All meetings were recorded.

Data was collected through the questionnaire, recordings of meetings, evaluations presented, and activities carried out throughout the short course. **Table 1** presents the details of each stage.

Table 1 — Short course stages

Meeting	Time (hours)	Purpose	Development
Before the 1st meeting	–	To analyze students' alternative notions about the research topic through an online questionnaire, in order to better understand the process as a whole and enable a rearrangement of the information that was going to be presented in the classes and discussions about such conceptions.	– The relationship between Art and Science; – Views of the nature of Science and Art; – The presence of creativity in both activities; – The scientific and artistic process; – Art and Science as areas of knowledge.
1st meeting	2	To present the research and its objectives; carry out a historical approach to the theme in order to improve notions about the Arts-Science relationship and each area's construction process.	– Research and interdisciplinarity; – Historical relationship between Science, Art and Society.
2nd meeting	2	To overcome mistaken and common-sense views on the Arts-Science relationship, presenting possibilities both in Teaching and in the applied field of each area, as well as the importance of creativity; to give feedback on the questionnaire, in order to provide more critical reflections on the alternative notions initially presented.	– The differences, similarities and possibilities between Art and Science; – The importance of creativity in Teaching; – The promotion of teaching for creativity; – Balance of questionnaire responses.
3rd meeting	2	To carry out discussions about the representational dimensions of Chemistry, its difficulties in teaching; the relevance of abstract content in Chemistry and models in science, so that Visual Arts graduates can have more in-depth and recent contact with such content and be able to contribute more to the creative process. Furthermore, to explain the activity and analyze the elements that students in each area consider important to be evaluated in the activities they will develop.	– The representational dimensions of chemical knowledge; – Abstraction in Chemistry; – Models in Science; – Explanation of the group activity.
4th and 5th meeting	5	To analyze how students from each area work together and how each one contributes to the process of achieving the same objective; to analyze the expression of creativity and imagination at that moment; and to understand how they deal with the creative act.	4th: Time to think about the problem they will solve, come up with the plan, start writing the lesson plan or research proposal, and plan the product. 5th: Time to make the products and put together the presentations.
6th meeting	3	To understand students' views on the short course as participants; to analyze the contributions and challenges of activities that involve interdisciplinarity and the creative act for the initial teacher education process; and to critically evaluate the short course and point out improvements to it.	– Group presentations and discussions; – Self-assessment; – Student evaluation of each group presentation; – Final Conversation Circle about the challenges and contributions of the process, creativity, the relationship between Arts and Science, and reflections on their initial education.

Source: prepared by the authors.

For this paper, we will analyze the structure of the short course presented in **table 1**, which was designed based on the references about the contextual view of creativity. We will point out at which moments the elements considered important for promoting teaching for creativity were present in the development of the short course. Furthermore, based on the data collected in the initial questionnaire, in the self-assessment and in the

discussions held in the Final Conversation Circle, we will point out some contributions of this teaching to creativity and interdisciplinarity for the initial education of undergraduates that could be perceived at the end of the process.

Developing creativity

First, it is important to better contextualize what was developed and observed at each stage of the short course. As indicated in the prior table, a 21-question questionnaire was administered to the students to analyze their alternative conceptions about various topics that would be explored later. The analysis of the aforementioned questionnaire (Leite, 2024) revealed that Visual Arts students exhibited a more contextualized and holistic understanding of their discipline compared to Chemistry students with regard to science. However, it should be noted that Chemistry students demonstrated a well-developed understanding of the nature of Art. This more refined comprehension in Art can be attributed to its closer connection with the public, making communication more effective, as well as the investment in historical, social, and philosophical discussions present in Art education programs (Art courses dedicate three times more hours to subjects of this nature when compared to science courses). This is one of the aspects that Science, in the context of Education, could learn from the Arts and consequently enhance its teaching and learning processes. It also highlights the importance of the History and Philosophy of Science (HFC) and interdisciplinary and transdisciplinary approaches in teacher education.

Although Art and Science are sometimes positioned as opposites, students generally point out more similarities (e.g. building knowledge about something, use of methodologies, they awaken emotions, respond to the current context, etc.) than differences between the two fields. However, Chemistry students were more likely to emphasize the differences, whereas Visual Arts students were more successful in recognizing similarities between the fields. This reinforces the idea that traditional Science education — often based on rigid, content-heavy, and mechanical approaches — limits students' ability to develop a complex and integrated understanding.

Even though creativity is considered fundamental to the educational process, when asked directly, some students still expressed the view that creativity is not particularly present in scientific practice. This indicates a certain confusion among some pre-service teachers, who perceive creativity as diminishing the rigor of research, leaving no room for imagination. This underscores the importance of explicitly addressing the role of creativity within science education, as well as providing opportunities for students to exercise and develop these skills in a more structured manner throughout their training process.

Since the questionnaire was administered before the short course began, these reflections and discussions took place in the second theoretical class. All the points covered in the questionnaire were integrated into the theoretical lessons, and afterward, a brief analysis of the responses was presented to the students, which allowed participants to reflect, deconstruct, and develop new meanings and understandings of the topics discussed. These moments were essential in fostering an environment conducive to the interdisciplinary practice that followed, as students began to establish more connections and deeper understandings with the other field of knowledge.

The discussions generated by students during the first session of the short course, which explored the historical relationship between Science and Art, contributed to critical reflections on conceptions of Art and Science, biases against the Arts, curriculum structures, how Science deals with mistakes, Art as experience, and other related themes. These reflections led students to reconsider their own educational processes.

The second session, in turn, focused on the similarities and differences between the two fields, as well as the potential of their relationship in education. The feedback from the questionnaire provided during this session sparked discussions about stereotypical perspectives (e.g. they are opposites, one only uses reason and the other only emotion, there is no method in art, etc.), the non-neutrality of both Science and Art, the undervaluing of creative expression as people grow older, the idea that Art goes beyond entertainment, the recognition of artists and scientists in society, the influence of context on how Science and Art are perceived, and the understanding that scientific and artistic outputs are approximations of reality. These discussions contributed to reflections on the nature of each field and helped develop a more critical perspective on them. These classes were essential in fostering communication, idea development and exchange, and improving participants' engagement, collaboration, and overall environment for creativity.

The third session sparked discussions that primarily helped students develop an evaluative perspective on their own creative process — an essential aspect both for understanding their own creativity and for fostering the kind of reflection that is integral to teaching practice.

An important observation at this stage was that while Visual Arts students proposed elements focused on the process — such as interaction among group members and the pursuit of balance between the fields in developing their proposal — Chemistry students were more concerned with the final outcome, emphasizing aspects like applicability and limitations. The elements proposed by each group complemented one another, contributing to the completeness of the overall proposal. Thus, this stage allowed students to exercise their autonomy and critical thinking regarding their creative process, while also encouraging them to consider important evaluative aspects that may not be as familiar to them.

The fourth and fifth sessions were dedicated to the development of the students' projects, and in the sixth session, they had the opportunity to present their work, followed by a concluding discussion of the entire short course. **Table 2** presents a summary of the proposals developed by each group.

Table 2 — Proposals developed by each group

	Objectives	Theme	Addressed Topics	Product
Group A	– Understand theoretical aspects of abstractionism, distinctions between figurative and abstract art, the main artists, and concepts of the movement; – Develop a work related to informal abstractionism that is subject to chemical reactions; – Enhance students' ability to identify the pH of compounds and substances through color changes; – Connect the experiment with both art and chemistry content.	Chemistry and Arts: Our World in Colors	– Informal Abstractionism (Freedom and creative autonomy in gestural expression; possible interpretations of the developed artwork); – pH (pH scale and colors of the red cabbage indicator; neutralization between acids and bases); – Pigments from food and everyday products (different sensations related to the obtained colors).	The students created an abstract painting using pigments extracted from food and household products, gradually altering the shades according to pH.

Objectives		Theme	Addressed Topics	Product
Group B	– Identify and understand the main characteristics of metallic bonding; – Relate chemistry concepts to artistic works; – Highlight the importance of understanding material properties in both Science and the Arts; – Promote national art; – Connect learned concepts to everyday situations.	Metal Alloys in Art and Chemistry	– Main characteristics of metallic bonding properties and their importance in Art and Science, such as high electrical and thermal conductivity, malleability, ductility, high melting and boiling points, tensile strength, and metallic luster; – Context of the works of Lygia Clark (Brazilian painter and sculptor); – Materials used by the artist.	Reinterpretation of the artwork *Bichos* by Lygia Clark. Students created a metal alloy sculpture to visually demonstrate the material's properties while also engaging with the artistic meaning of the piece.
Group C	– Showcase the diversity of perspectives and visual exploration processes in students' daily lives; – Encourage the observation of chemistry concepts (mixtures, natural phenomena, chemical processes) and art elements (photography, composition, color, angle, image creation) outside the classroom; – Stimulate and enhance the use of smartphones in pedagogical and artistic processes such as photography.	Artistic-Scientific Visual Laboratory: A Collection in Progress	– Photography techniques, soil, lichens, medicine, liquids and mixtures, preserves, oxidation; – The chemistry and art of everyday life.	Create a virtual photographic archive to be continuously updated by students, aiming to develop photographic skills and the practice of exploring and perceiving nature, daily life, and its phenomena through an aesthetic and questioning look.
Group D	– Study the history and general properties of radioactivity; – Simulate the alpha and beta decay of radioactive elements; – Research applications of radioactivity in everyday life; – Understand alternative conceptions about the topic; – Stimulate imagination by attempting to personify the concept.	Ionizing Radiation	Radioactivity, Everyday Life, and Drawing	– Creation of animated characters (in GIF format) to visually represent the concept of radioactivity.
Group E	– Identify and name inorganic functions; – Balance and name chemical reactions in which these functions interact; – Apply the concept of electronegativity to the emergence of the first inorganic functions; – Stimulate imagination and creativity through the development of narratives and character creation.	Oxides (Booklet *Primitive Planet*)	–Organic functions; –History of life on planet Earth; –Alternative artistic and graphic representation of inorganic functions.	Creation of a booklet containing narratives and characters that reference organic functions. It incorporated historical and chemical content (origins of life on Earth and the role of oxides in this phenomenon).

Source: prepared by the authors.

As the objective of this article is to reflect on the structure of the short course rather than the products itself, we will focus on explaining how the elements of Teaching for Creativity were important for fostering and expressing this skill in future teachers. A discussion on what was produced can be found in Leite (2024).

As previously explained, the development of Teaching for Creativity needs to be considered three important factors: the individual, the group, and the environment they are part of. The individual dimension involves both specific aspects of their personality and their cognitive and creative abilities, as well as their intrinsic motivation (Alencar, Fleith, 2003; Kneller, 1978; Zavadil; Tschimmel; Silva, 2016). Most of these elements

could be identified from the recordings of the practical classes and discussions in the conversation circles, and the presence and absence of such aspects proved to influence the development of the whole creative process.

These elements were not observed from a psychological perspective or analyzed using psychometric tests, as some studies do to understand the creative process (Kind; Kind, 2007). However, based on the aspects discussed by the theoretical references (Amabile, 1983, 1997; Sternberg, 1988; Zavadil; Tschimmel; Silva, 2016), it was possible to identify their expression throughout the conversation circles and group work. That is, we could see how different personalities, knowledge, previous experiences, motivations and skills influenced and differentiated the processes developed by each group.

The observation of these stages of development and product creation within a mixed group highlighted how individual characteristics — such as cognitive and creative abilities, knowledge, experience, and intrinsic motivation — influence the development of creativity. Moreover, these factors not only impact the group and the environment but are also influenced by them. This reinforces the idea that everything is interconnected and that the complexity of these connections' manifests both on a personal level — meaning our relationship with ourselves and our surroundings — and on an epistemological level, as the knowledge we construct is also linked to our personal experiences and, consequently, to the environment we are immersed in.

The initial contributions made by each group member were based on their closest personal experiences, such as the research topics they were developing in their courses or past practices they had already engaged in. This reinforces a key argument presented here: imagination and creativity are tied to the body of knowledge and experiences that we possess, making the material available in our imagination richer for forming new associations and reinterpreting the experiences of others.

Enabling diversity is essential for fostering knowledge exchange among students from different fields. In an effort to balance the approach between disciplines, Chemistry and Visual Arts students took turns explaining content, discussing the possibilities and limitations of each idea. It is through this dynamic process that concepts are explored, understandings are refined, new knowledge begins to take shape, new connections and meanings emerge, and creativity is developed.

This highlights the importance of incorporating interdisciplinary work into teacher education from the very beginning and fostering more interactions between diverse groups. Such experiences push students out of their comfort zones, offering challenging opportunities that stimulate creativity, the integration of knowledge, and the exploration of new pathways. As these elements relate to the individual nature, they cannot be controlled or thought about a priori, like the aspects involving the environment and or the group can. However, since our starting point is a contextual view of creativity, we understand that all the elements presented so far influence one another. That is, the aspects of the environment and the groups influence the individual, and vice versa.

Regarding intrinsic motivation, for example, Zavadil, Tschimmel and Silva (2016, p. 196, own translation) point out that

> Although intrinsic motivation is an individual characteristic, some external factors and the activity in which the individual is involved can influence it. Furthermore, teamwork and the environment also affect personal motivation, which in turn plays a decisive role in the creative design process.

The participants of the short course noted this intrinsic and extrinsic influence on the individual's creative process from the beginning. In the initial questionnaire, when asked to complete the phrase *I would be more creative if...*, respondents offered answers such as "*I were willing to develop creativity. It were also encouraged. If I found a purpose for it". If I were better paid in my field of work* [...] *had more recognition". "Work with time and freedom*"; "*If I had the freedom and opportunity to work on my ideas in a free and practical way throughout my learning process". "There were more subjects with an approach focused on the objective of the course, which is education and not industry*".

This finding aligns with the contextual view of creativity presented in this paper, which states that the creative process is complex and dynamic. The impact of this phenomenon is not solely determined by individual factors or environmental influences. Both are interconnected, influencing one another, and carry out exchanges at all times. According to Vygotsky (2009), this process involves collecting elements from nature, disassociating them, modifying them, associating them again, crystallizing new ideas, and giving a new meaning to it at the moment called appreciation. Such steps are not linear and can be repeated several times. It is evident that creators are the result of their own time and environment.

> […] their creation is driven by needs that preceded them and is also informed by possibilities that exist beyond them "[...] no invention or scientific discovery can emerge before the material and psychological conditions necessary for its emergence. Creation is a process of historical inheritance in which each succeeding form is determined by the previous ones (Vygotsky, 2009, p. 42, own translation).

Table 3 and **table 4** were prepared based on Zavadil, Tschimmel and Silva (2016), who group the general and specific elements about creativity from the main reference studies in the area, and also the studies by Sternberg (1988), Amabile (1983, 1997), Csikszentmihalyi (1988) and Woodman, Sawyer and Griffin (1993). They show which aspects are considered important for the development of creativity in the Environment and the Group. They also show in which times such elements were thought of and were present in the short course.

Table 3 — Aspects involving the environment

General aspects	Specific aspects	Short course moments
Field / Domain	Practice and knowledge	Throughout the first three classes, students worked and discussed a variety of topics. In the final three classes, students had the opportunity to put their knowledge into practice.
	Community of experts	Class 6 — Presentation of each group's creation, evaluation / feedback from colleagues and the researcher.
	Appropriate and challenging task	Yes, the theme was consisted with the short course, requiring time, group work, knowledge and creativity from the students.
	Time for work	8 hours in total (2h for creating the idea, 3h for developing the plan, 3h for presentations and discussions)
	Financial resources	Not required
	Material resources	There were no specific materials required; each group could decide what to use.
	Information	Throughout the entire short course.

General aspects	Specific aspects	Short course moments
Management / leadership practices	Communication	It was maintained at all times by the researcher during classes 1, 2, 3, and 6, but only when requested during classes 4 and 5, in order to avoid interfering with the groups' creative processes.
	Recognition, Constructive Assessment and Feedback	Especially in class 6, after each group's presentation, and at the end (final conversation circle) of the short course.
	Freedom	There was no imposition regarding students' participation, expression, and communication.
	Clear goals	In the first class and reinforced in the third class when explaining the activities.
	Highlighting of individual skills	This point was not well developed. Ultimately, we realized that group skills were highlighted more.
	Indications for taking risks	In practically all classes, an element was available and highlighted so that students would not feel limited to choosing the most obvious way to solve the activity.

Source: prepared by the authors.

The environment, from a contextual perspective, is one of the main elements that influence the development and expression of creativity. So, all aspects identified as important were included in the initial plan for structuring the short course and preparing the researcher as its mediator.

With the exception of highlighting individual skills, all specific aspects mentioned in **table 3** were articulated and were present in the development of the short course, according to the initial planning. However, although almost half of the short course's time was dedicated to the practical part, some participants indicated time as a limiting factor in the final evaluation. Despite recognizing that every short course has little time to develop its activities, they said that if they had more time available, they would probably have come up with more creative ideas, as in the excerpt "*It would be nice to have more time to work on ideas more calmly*."

This corroborates studies that point to time as a crucial aspect for the development of the creative process (Jackson, 2014; Zavadil; Tschimmel; Silva, 2016). However, within the educational context, the time given to a certain activity needs to be reached to a limit, which indicates losses throughout the process, but it has to be enough for it to be carried out satisfactorily — as was the case with the short course in which all groups developed their work.

Developing an activity in a given time also influences the nature of the challenging task and the choices made by each person. Therefore, this limit, as long as it's enough to be able to carry out the challenge, can also favor the development of creativity.

Regarding the challenging task itself, it required group work with students from different courses, and its proposal was to work with the abstract and seek an interpretation that involved both areas. The task fulfilled its objective in terms of making students overcome passivity and explore new paths in the construction of knowledge. The intensive interactions observed in the recordings of each group made it possible to observe the processes and the knowledge shared between the students. When asked about the challenges faced throughout the activity, it was almost unanimous that the biggest challenge was finding a balance between the two areas, so that both could be addressed: "*The moment that took me the most out of my comfort zone was thinking about the product in a way that equally covered both areas*"; "*what drove me away of my comfort zone was precisely thinking about this content trying to unite the two subjects*".

According to Favarão and Araújo (2004) and Fazenda (1994), interdisciplinarity, which was explored in this short course, allows a new way of looking at reality based on an exchange between different forms of knowledge, aiming to build new knowledge and solve problems. This more comprehensive view from exploring the potential and limitations of each area contributes to the development of creativity.

The search for overcoming fragmentation is consistent with complex thinking and interdisciplinarity, and it favors the creative process. The challenge of finding balance between areas corroborates Lück's (2001, p. 61, own translation) vision of interdisciplinarity:

> The purpose of interdisciplinarity is not to devalue the disciplines, but rather to develop them sufficiently so that they can be integrated with other disciplines, forming a circle of knowledge in pursuit of knowledge. Disciplines provide the information, elements, and ideas necessary for this construction. As knowledge is an unfinished phenomenon that is impossible to fully encompass, interdisciplinarity is a continuous, never-ending process. Upon entering the interdisciplinary realm, individuals will encounter obstacles and habits of fragmented, simplistic thinking in their constant pursuit of a comprehensive vision of reality.

In this sense, the great challenge of thinking within interdisciplinarity is also its great contribution, and this was noticed at the end of the short course, as we can see in the following speech "*working together with the chemistry students was helpful because I could develop a more sensitive perspective in relation to an area that I considered to be exact*, [...] *this short course made me more accepting of help from other areas of knowledge and had an expansion on inter and multidisciplinary classes*".

Another limitation related to the environment indicated by the participants was the fact that short course was developed online, as can be seen in this excerpt: "*Perhaps the online meetings were a limitation, since student interaction in the construction of the product idea and its development faces barriers that would result in a greater exchange of experience in person*." For some students, if the short course was developed face-to-face, group interaction would be richer and the construction of products more creative, as there would be a more real exchange with the world. This highlights the importance of communication, another essential point discussed by the theoretical references.

Although we are aware of the limitations of online classes, which became even more apparent during the COVID-19 pandemic, it is interesting to consider how the influence of the environment influences the choices we make. This reality prevented many ideas from coming into being, however, it allowed students to explore paths they might not have considered if they were face-to-face.

Table 4 presents the elements that influence creativity development in groups, as outlined by Zavadil, Tschimmel and Silva (2016), as well as Woodman, Sawyer and Griffin (1993).

Table 4 — Aspects involving the group

General aspects	Specific aspects	Short course moments
Group characteristics	Diversity	Chemistry and Visual Arts Students.
	Size /cohesion	There were six groups, each with 5 to 6 members. At least two members from each area were in each group.
	Trust	This aspect developed throughout group work.
	Interdependence	This aspect developed throughout group work.

General aspects	Specific aspects	Short course moments
Mind models	Shared processes	This aspect developed throughout group work.
	Shared knowledge	Present in both theoretical and practical classes.
	Communication	Explored by individual groups throughout the discussions and conversation circles during the short course, and within each group of students formed to complete the activities.
	Teamwork	It began in class 3 and developed mainly in meetings 4, 5, and 6.

Source: prepared by the authors.

Regarding aspects involving the group, it is possible to reflect on both the class as a whole and on the small mixed groups formed by students to carry out the activities. Diversity and size/cohesion were considered in the strategy designed to structure the short course, including students from Arts and Chemistry courses who were together from the beginning of the process.

Following these aspects, when creating groups to carry out the activities, it was requested that each group had at least two students on each course, so that there was a similar number of students on each course. Also, so that there would be richer and more effective communication, as well as greater sharing of ideas both between members of the same course and with other participants. Such diversity was essential for the exchange of knowledge between members of each course.

In an attempt to seek a balance between the areas in the approach taken, Chemistry and Visual Arts students took turns explaining the content, the possibilities and limitations of each idea.

This moment represents an important aspect of the interdisciplinary process experienced by these students, because, according to Pátaro and Bovo (2012),

> To work from an interdisciplinary perspective, therefore, the knowledge already produced — which often remains separate from each other — must be integrated. That being said, the movement towards interdisciplinarity can be seen as a way of promoting dialogue between knowledge, which are no longer seen in a fragmented way and start to collaborate mutually to face the complex problems that reality poses to us. This dialogue refers not only to the interaction between two or more subjects, but presupposes joint work, which can occur both between researchers and teachers at school. This collective work is, at the same time, a way of recognizing the limitations of the subjects and a way of seeking knowledge that can only be produced through articulation. The principle that underpins the concept of interdisciplinarity is that no area of knowledge can be considered complete by itself (Pátaro; Bovo, 2012, p. 58, own translation).

This collective and interdisciplinary work is essential for the development of the creative process, as this exchange enriches our experience and imagination, two necessary elements in the act of creation. As Vygotsky (2003) and Bronowski (1983) point out, both creativity and imagination are based on human experience, on reality. The richer our experience, the more elements are available to be correlated and reworked by our minds.

The analysis of group work shows that when there is a common goal to be achieved by a team with individuals from different backgrounds and experiences, that is, a collective system, there is a greater tendency to develop creative connections. By mapping the shared knowledge among group members, it becomes clear how the diversity of perspectives and experiences stimulates the creation of new ideas and

the re-signification of other forms of knowledge. This occurs because each person possesses a body of knowledge, experiences, and skills that, when combined with another's, enhances our rational, imaginative, creative, and intuitive capacities, thereby amplifying the possibilities for combining and recombining information. This diversity is crucial for overcoming conventional patterns of thought and, consequently, for finding solutions to complex problems.

Within each group, learning is collective. The sharing of knowledge and experience enriches interpersonal relationships among members, creating a safer environment for expressing ideas and enhancing the learning of everyone involved.

However, the opposite is also true: when communication is not very efficient, when there are interpersonal conflicts, or when the shared knowledge diverges too much from the understanding of other members — such that they are unable to re-signify the information for themselves, making it difficult to form new connections and propositions — it hinders the creative flow.

For example, considering all six groups, only one (Group D) did not meet the activity's proposal of coming up with an approach to the created product (giving shape to an abstract subject of Chemistry) that involved both areas, bringing an artistic, scientific and philosophical view of it, that could be considered in both Chemistry and Arts Teaching.

When analyzing the teamwork of this group, it was possible to notice that there was great difficulty in communicating and sharing knowledge. These students, specifically, got stuck in a conventional movement of separating theory (which was left to Chemistry students) from practice (Arts students). There were a few processes that were actually shared and built together, and the final approach ended up being content based within the scope of Chemistry. Unlike the other groups, the lack of development of these aspects made these participants present the opinion that the activity pointed out one area superior to another in their final self-assessments. Also, that Art could not contribute in a deep way, and that their skills were not more explored due to the interdisciplinarity.

When analyzing how the other groups developed their work and how each of these aspects were present not only in the construction of the product itself, but also in the ideas reveals how the relationship between peers influences and contributes to the development and expression of creativity in group work, as explained in this excerpt: "*Fortunately, communication was a challenge overcome, because when the proposal was chosen and well understood by everyone in the group, the creative and construction processes went very well*".

The analysis of how the groups developed their work, in general, highlighted how the process of constructing knowledge and creativity is dynamic and nonlinear. Ideas are woven together like in an act of sewing, where sometimes stitches are undone, others are revisited, and new ones are added as interactions occur. The final embroidery of this sewing represents and makes visible the complementarity of different kinds of knowledge. The knowledge of Chemistry and Visual Arts was not exclusive, but rather responsible for the creation of a complex piece that allowed interpretations based on this web of knowledge. That is to say, to fully understand it, you have to look at it through a kaleidoscope rather than a telescope, because it contains different kinds of knowledge.

Another very important contribution that this stage of interdisciplinary group work reveals to us is the concern with a more human and philosophical perspective regarding the construction of the idea as a whole, which the encounter with the Visual Arts can

provide for Chemistry. It was evident how most of the Visual Arts students took great care with this dimension, and this was essential in stimulating more philosophical views from the Chemistry students. Art has the ability to sensitize perception, and bringing this into Science Education can help overcome certain misguided and limiting views of nature, improving our creative capacity to think about the world and its issues.

The works that the groups developed also demonstrated the plurality of relationships and interpretations that can arise from the meeting of Chemistry with the Visual Arts, that is, from interdisciplinarity. This diversity lies not only in the product and the varied artistic languages it encompassed, but also in the reflections generated throughout the process and in the final interpretation given, which includes discussions on the body, daily life, context, feelings, truth, error, ethics, the environment, concepts, beliefs, teaching, and more.

This is an important result achieved by the research, as it demonstrates the potential of the proposal and shows how the relationship between Art and Science can contribute not only to the development of creativity, but also to enhancing the nature of knowledge for future teachers, whether in Arts or Sciences, since this encounter generates mutual contributions.

Beyond these points observed from the researcher's perspective, considering the evaluations from the students themselves who participated in the research, the short course and, consequently, the contact with people and knowledge from the other area, generated the following contributions: expanded reflections and teaching possibilities; the opportunity to experience interdisciplinarity and collective work; enhancement of notions and exploration of new ways of thinking; development of creativity; in addition to the stimulus to step out of the comfort zone.

All that we've discussed so far illustrates the idea that creativity is not limited to its final product, just like Arts or Science. In other words, we cannot understand Arts, Science, or the creativity that brings them together without looking at the processes that build them, which involve the individuals and their contexts. Furthermore, as Vigotsky (2009) argues, the creative act does not end in the final product, but rather in the resignification that others make for themselves when appreciating the creation, that is, the individual, the environment and creativity are connected as a whole.

Therefore, reflecting on teaching for creativity is extremely important to know all the aspects that influence this complex process, full of variables. From this perspective, the teacher does not place all the responsibility for the development of creativity in the student himself, but is also recognized as an important element in the same process, improving his own practice, which includes: encouraging new ideas; promoting an environment prone to the expression of thoughts, evaluation and thought out methodologies; interest in the student's learning process; among other aspects that Alencar and Fleith (2004) discuss in *Inventory of Teaching Practices that Favor Creativity in Higher Education*, which were considered by the researcher as a mediator of the short course.

Final remarks

Creativity, despite being an essential point for all human activity and creation, is developed and expressed at different levels when we analyze Teaching, especially Teaching of Natural Sciences. The fact that students end up losing the space that allows and encourages them to take risks on new paths and explore different ideas

throughout the school stages (Basic Education to Higher Education) is nothing new. In most cases, they are progressively encouraged to follow fixed ideas, procedures and laws, without the possibility of questioning, playing an active role or trying out other solutions, which were all necessary steps throughout the history of human knowledge. So, it is important to know the necessary elements to develop teaching for creativity, that is, the type of teaching which aims to develop this human ability. By covering all areas of knowledge, creativity becomes an interesting key element to be explored by interdisciplinarity.

This short course, which explored the interdisciplinarity between Arts and Science, clarified the importance of each aspect highlighted as necessary in the development of creativity from a contextual perspective. That is, it demonstrated that not only the individuals and their personal characteristics interfere in the creative process, but also the group and the environment in which they are. Therefore, when aiming to teaching for creativity, teachers have to keep in mind not only the attitudes related to their teaching practice that will favor the development of creativity in their students, but also the entire classroom (both the groups of students and the physical environment) and the activities and strategies designed. It is also interesting that students themselves know these aspects so that they can work with each other and consider them in group work.

Based on the results and statements obtained throughout the short course, it is possible to say that interdisciplinarity, when combined with a proposal of teaching for creativity, is capable of promoting a number of contributions to teaching, especially regarding teacher education, since students are challenged to make knowledge connections, promoting complex thinking, finding balance with knowledge from another area, placing themselves in an active position in knowledge construction, creating and materializing an idea together. So, interdisciplinarity, which is much discussed theoretically in teacher education courses, can actually be experienced. Creativity stops being secondary or neglected to become a central aspect of the educational process, promoting critical reflections on teacher education and the nature of knowledge that is not scientific or artistic, but rather human.

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Conflicts of Interest

The authors have no conflicts of interest to declare.

Author' Contributions

Mônica Regina Vieira **Leite**: Conceptualization (equal); Data curation (lead); Formal analysis (lead); Funding acquisition (lead); Investigation (lead); Methodology (lead); Project administration (equal); Resources (lead); Software (lead); Supervision (equal); Validation (equal); Visualization (lead); Writing — original draft (lead); Writing — review & editing (lead).

Sandra Regina Teodoro **Gatti**: Conceptualization (equal); Project administration (equal); Supervision (equal); Validation (equal).

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Data Availability Statement

The research data is contained in the body of the manuscript.

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