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Art, Science and Culture in Dialogue with Physics Teacher Education[+*]

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Abstract

The context for this study is the initial education of physics teachers, particularly exploring the intersections between art, science, and culture to reflect on the possibilities for more humane, contextualized, and integrated teaching. Based on the course Art-Science-Culture and Physics Teaching, in a physics teacher education program at a Brazilian public university, we seek to reflect on the extent to which integrating art, science, and culture can contribute to physics teaching (PT), based on the voices, reports, and insights constructed together with pre-service teachers in a theoretical-experimental research approach. The methodology is qualitative. We utilize an initial questionnaire, classroom observations, and think-aloud protocols, with final records captured in a concluding questionnaire, involving 23 participants. The data were organized through textual discourse analysis, leading to the creation of analytical categories and a metatext at the end. Among the results, we highlight the participants' recognition of innovative methodological approaches as a potential means of connecting physics to everyday life, making classes more engaging and interactive. The study revealed that the intersection of art, science, and culture is a fertile ground for considering new possibilities for PT and an important avenue for rethinking teachers' initial education.

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I. Initial dialogues

"Reinventing!"

This term alludes to the new—to recreating, reflecting, and redesigning, or to seeking different perspectives on what is already established. Reinventing also involves updating and innovating, where a new approach can unveil previously unknown paths for emerging problems. Contemporary society, with its constant and sweeping changes, continuously compels individuals to reinvent themselves, whether in their way of life or in professional matters. Reinventing nourishes the rhythm between lived experience and the living being, aligning our lives and actions with a sense of belonging to the present. Examples of this movement can be found in social relations and in increasingly technological and diverse forms of communication.

Reinventing is always complex and often difficult to carry out, since it moves away from what we could call a comfort zone. However, the continuous need to reinvent also pervades educational contexts, which are integral and essential parts of society. Despite their traditional practices, today's schools are very different from what they once were, whether in form, content or, especially, in the public they serve. Such perceptions are increasingly calling for changes that can keep up with contemporary challenges, be they structural, curricular, or related to methodological innovations. The fact is that innovating educational practices presupposes viewing the teacher as a fundamental agent of this innovation (Flores; Flores, 1998). This context prompts us to reflect – and perhaps rethink – how those who guide, sustain, and reinvent educational and innovation processes in schools have been educated. In other words, it leads us to think about "teachers!"

Leite et al. (2018, p. 722) say that "*in contemporary world, among the several challenges facing teacher education, a critical one is to train practitioners who can meet multiple emerging demands in the educational context, especially regarding school as a locus of action,*" a major challenge to be addressed in school organizations (Avila; Souza, 2020). Libânio, Oliveira, and Toschi (2017, p. 30) further argue that teachers

> *can no longer be mere information conveyors, but must be researchers both attentive to the individual and sociocultural peculiarities of students and sensitive to unpredictable teaching situations. They must also be active and reflective participants in the teaching team, discussing in their group their conceptions, practices, and experiences* (Libânio; Oliveira; Toschi, 2017, p. 30).

Such considerations pervade initial teacher education. These authors add that these aspects require teacher education to "*set specific requirements for initial and continuing teacher education*" (Libânio; Oliveira; Toschi, 2017, p. 30). That said, this article presents and discusses a methodological innovation initiative that was employed in the training of physics teachers, based on the intersections between art, science, and culture. The goal was to investigate and reflect on how the discipline "Art-Science-Culture and Physics Teaching," taught in a physics teacher education program at the Federal University of Triângulo Mineiro at Uberaba, MG, can contribute to initial physics teacher education by integrating interdisciplinary approaches that connect different fields of knowledge. The study also sought to understand how the pre-service teachers perceive interactive and contextualized activities, exploring the potential of different didactic-pedagogical strategies in connecting physics teaching to everyday life. Some guiding questions support the discussions throughout this text, such as: To what extent can the intersection between arts, science, and culture contribute to physics teaching? How to bring physics teaching closer to everyday life, while also considering students' different skills in this process?

These concerns are situated in a research field that has been highlighting significant challenges in and for the education of physics teachers, as well as for methodological innovation in teaching contextualized physics that might arouse students' interests (Schnetzler, 2000 2021; Nardi, 2009; Anjos, 2013 2021; Testoni; Abib, 2014; Carvalho; Sasseron, 2018), in addition to political considerations related to teacher education (Ostermann; Rezende, 2021; Deconto; Ostermann, 2021). Among so many challenges presented by the literature are weaknesses in initial teacher education, as well as the methodological aspects of how to teach physics. For example, when approaching the teaching of current physics, Moreira (2017) begins his reflections by pointing out that basic education physics is in a crisis, as it is outdated "*in terms of content and technologies, teacher-centered, behaviorist, focused on training for tests, and addressing physics as a finished science, as presented in a textbook* " (Moreira, 2017, p. 3). A scenario that leads us to reflect on the contributions of teacher education to facing these issues, specifically in the context of this study, about the intersections between art, science, and culture as possibilities to make teaching both contextualized and integrated to students' everyday life.

II. Physics teacher education and the contemporary challenges

Training teachers is far from being an easy task, since it involves so many variables, processes, and the need for legislation compliance, besides being the subject of constant struggling in society. When we look at physics teacher education, the context becomes even more specific. For Borges (2006, p. 136), by the end of basic education, students are expected to:

> *(i) know the main science models; (ii) have learned how to model phenomena, events, and situations; and (iii) have developed an ability and acquired a habit of searching, evaluating, and judging the quality of the arguments and evidence available for producing new knowledge about the addressed phenomena and problems.*

The question is: How to do this without addressing the education of the conductor of this orchestra called Education? Borges (2006) emphasizes that among the various difficulties meeting these precepts, teachers have been struggling to promote students' critical thinking, as opposed to simply memorizing physics and its concepts. The author argues that "*teachers do not do so by mere chance, but because they are reproducing the approach to and methods of physics teaching that they experienced in their own education. They therefore reproduce what their former teachers taught them tacitly and unconsciously*" (Borges 2006, p. 136).

Thus, there is a pressing need to promote change in this teacher education scenario. However, any change process can be as encouraging as it is threatening (Messina, 2001), as it "*implies denaturalizing or taking some distance from the habitus that constitutes us, which is as structuring as it is structured, separating ourselves from these ways of feeling, thinking, and acting*" (Messina, 2001, p. 228). In the context of physics teacher education, changing involves re-signifying training paths to better understand and contribute to that training, in relation to the teaching and learning processes. It is a journey across troubled waters, leaving behind a passive and mechanized teaching "riverbank" towards another bank that is active, participatory, collaborative, and investigative, where teacher education involves building bridges.

Thus, the difficulties contextualizing physics contents lead us to reflect on how these aspects have been discussed in initial teacher training, justifying the themes and reflections we propose in this study. Moreira (2018) warns us that during initial teacher education, future teachers usually have been trained for a relationship with traditional teaching, based on expository classes and problem lists, and these factors reflect on their future performance in basic education classrooms (Testoni; Abib, 2014). The author also comments on the lack of up-to-date physics contents and approaches – such as modern and contemporary physics – in the curricula, and they present a caveat:

> *"More physics" no longer means more content to be memorized, mechanically stored. It is necessary to think about how to teach these contents, paying attention to specific didactics, didactic transfer, how to approach physics in order to arouse students' interest, intention, and willingness, without which learning will not be significant, but simply mechanical, to "pass the tests"* (Moreira, 2018, p. 76).

Sharing these ideas, Carvalho and Sasseron (2018, p. 43) argue that "*there is no denying that teachers need to know the content they will teach, but they also need to know how they will teach it to students*." In other words, to teach physics, it is undoubtedly necessary to know physics, not losing sight of the epistemological and ontological dimensions of scientific knowledge (Pietrocola, 1999). This basic premise is not under discussion. However, what authors such as Moreira (2018) and Carvalho and Sasseron (2018) point out is for us to also think about initial teacher education, "how" to teach that physics so that it can makes sense to students and arouse their motivation to learn. Thus, there is a pressing need to consider different ways of innovating physics teaching, promoting argumentative processes in the classroom, reflecting on the inclusion of investigative activities, and fostering contextualized teaching –

that is, "*ridding ourselves of teaching for tests, metaphorically, abandoning the narrative, chalkboard-and-textbook model*" (2017*, p.* 13)*,* as well as moving away from forms of teaching that rely solely on expository methods, with content that lacks contextualization from other areas (Testoni; Abib, 2014). This approach is supported by the ideas of Valente (1999, p. 31), who states that the "*pedagogical change widely sought is the transition from an education totally based on information transmission, on instructions, to the creation of learning environments in which students perform activities and build their knowledge*". Therefore, this is a major contemporary challenge for and in initial teacher education, particularly in physics.

In addition to the epistemological and ontological dimensions and methodological obstacles that emerge in physics teacher education, it is also important to reflect on the social and educational transformations that have significantly impacted teaching over the last decades. Gasparini et al. (2005) point out that until the 1960, teaching was associated with job stability and social prestige. Since the 1970s, the increase in social demands for access to rights and services, such as public education, resulted in an expansion of the civil service workforce and the provision of free services. This context has triggered significant transformations in teaching practice, making it broader and more diverse in its responsibilities. In the contemporary world, the role of physics teachers goes beyond the mediation of knowledge in the classroom to encompass school management activities, pedagogical planning, and interaction with families and the community around the school. As the authors explain, this stems from the fact that "*the school system transfers to practitioners the responsibility to bridge institution gaps*" (Gasparini *et al*., 2005, p. 191). This overload of tasks occurs in a scenario marked by scarce human resources, strict evaluation mechanisms, and limiting, private-based, and utilitarian educational policies (Deconto; Ostermann, 2021). As Jacomini and Penna point out (2016, p. 185), in addition to the "*loss of autonomy at work and the increase in tasks to be performed by teachers, there are teacher salary and career issues that impact their professional prospects, affecting even the recruitment of future teachers*."

In the case of physics teaching, the challenges are even more evident. In addition to poor working conditions and a progressive identity loss by physics in the curriculum, the contents taught remain outdated (Moreira, 2018), reflecting rather the 19th century than the scientific and technological demands of the 21st century. This disconnection from the present contributes to students' lack of interest and hinders their understanding of a physics applied to practical everyday life. This is a context that requires collective efforts to be reversed. It is essential to invest in professional appreciation, curriculum updating, and the necessary infrastructure for modern and interactive pedagogical practices in order to transform physics teaching into a meaningful and inspiring experience, aligned with the demands of the 21st century and capable of arousing teachers' and students' interest and creativity.

Attentive to the challenges of physics teaching and physics teacher education, and considering that such education "*is known to be complex, especially if we reflect on teachers' role and social function*" (Leite *et al*., 2018, p. 723), we discuss the results of a study conducted with pre-service physics teachers about arts, science, and culture. But before this, we present the approaches, actions, and activities developed with the pre-service teachers on these topics, as they participated actively in constructing the knowledge that was approached. Therefore, it is important to reflect on the possible intersections between art, science, culture, and physics teacher education, which we do in the following section.

III. Art, science, and culture in dialogue: What do we agree on?

The intersections between art, science, and culture can be seen centuries ago. Over time, the three created a collaboration relationship that frequently aimed to explore and understand the world around us, even if in different ways. According to Lopes and Dahmouche (2019, p. 308):

> *Today, art and science may seem to be two distant and antagonistic fields, but the relationship between both, which are subdivided into other fields, was not always a distant one. Renaissance painters applied mathematical principles to create an illusion of volume and proportion to images in order to portray nature realistically. Doctors, in turn, resorted to artists, who, by recording dissections, such as Rembrandt's 'Anatomy Lesson,' documented the human body, generating unprecedented study sources. Escher used geometry to create a reality apart: infinite and fanciful [...].*

The authors provide an insightful reflection on the complex and constantly evolving relationship between art and science. While the two sometimes moved apart, possibly due to excessive scientific rigor or artistic subjectivity, it is undeniable that both have the potential to feed into each other and contribute to a more holistic understanding of the world. In addition, the interaction between these two spheres, supported by cultural aspects, can contribute significantly to creating more curious and creative individuals capable of addressing contemporary challenges with an open mind and a broad perspective.

We can thus see that their established relationships are inherently interdisciplinary. However, in schools, we can still see the reflection of a traditional and outdated educational approach that leads students to lose interest. The school environment continues to take a limited approach to disciplines, with little or no integration between what is taught and lived reality. These contexts can lead us to reflect on the ideas advocated by Professor João Zanetic (1943-2024 – *in memoriam*), particularly on his approach to physics as culture (Zanetic, 1989; 1996; 2009; 2006a; 2006b; 1997). In his words,

> *When it comes to culture, physics rarely appears in the argument. Culture is almost always evoked with literary work, a symphony, or paintings; erudite culture, in a word. Such culture, international or national, brings to mind a painting by Picasso or Tarsila, a symphony by Beethoven or Villa Lobos, a novel by Dostoevsky or Machado de Assis, while popular culture makes you think of Capoeira, a samba song*

> *by Noel, or a tango song by Gardel. Hardly ever, though, is culture linked to Godel's theorem or to Maxwell's equations!* (Zanetic, 2005, p. 21).

Zanetic (2006a) defended the importance of a more creative and powerful approach to physics, emphasizing the need to build bridges between art and science, fed by culture. These bridges can provide a richer, more meaningful educational experience, encouraging students' curiosity, creativity, and engagement.

> *This apparent incongruence in seeking to connect science and art was addressed by several authors, some contrary and some supporting this intersection. I obviously include myself among the latter, believing that mutual contamination between these two cultures is useful not only to interpret the world, but also to transform it, as taught by Karl Marx* (Zanetic, 2006a, p. 57).

Professor João Zanetic criticized the teaching of physics that followed traditional models, decontextualized and restricted to memorizing formulas and resolving exercises (Lima; Catarino, 2024). And, in contrast to critiques, he argued that for a structural change in physics teaching, a change in basic education was also necessary, with an increased number of classes aimed at studying physics, adopting teaching focused on physics concepts to the detriment of formulaic mechanization, and including experimentation, thus allowing students to understand science and its applicability to everyday life (Lima; Catarino, 2024). By expanding these directions, we find in the National Curriculum Parameters (NCP) a rough indication of the connections between art and science, highlighting both ways of investigating, interpreting, understanding, transforming, and establishing links with the reality we live in. However, while these documents indicate the importance of scientific and artistic knowledge in students' education, there is no direct mention of integrating both types of knowledge or how this might take place. Despite these points, while interdisciplinarity is a principle highlighted in the NCP, many teachers still perpetuate traditional education practices, replicating the methods that were used by their own teachers when they were students. This resistance to change makes it difficult to break the barriers for a comprehensive and engaged citizen education.

It is worrying to note that interdisciplinary activities are often prevented by the teachers themselves, demonstrating a gap between educational discourse and classroom practice. Given this scenario, it is essential to direct our attention to the training process of education professionals in order to prepare them to develop activities that promote a more integrated and meaningful learning for students. Several teachers-researchers have dedicated themselves to studying the process of teacher education, and the context of physics teaching is no exception. For example, Santos, Santos, and Germano (2024) present a bibliographic survey of research on the relationships between "physics and culture" and "science and culture" as found in the journal *Caderno Brasileiro de Ensino de Física* (CBEF). The authors considered the time frame from 1990 to 2022, and identified only 31 works within a universe of 1,100 productions. Among the selected studies, the most significant intersections were found between “physics and culture,” identified in studies that presented an interface between science and art. This relationship was found in 4 studies that directly addressed this relationship, though without specifying artistic languages. Seven studies addressed visual and performing arts (theater, cinema, magic, and painting), whereas nine others discussed literature-related issues (literature, *cordel* literature, poetry, and comics). Five studies directly related to the intersection between physics and culture were also found. Closing the analyses, the authors cite a group that they classify as “contexts,” which comprised an ethnographic study and works “*intended to express or intertwine physics with aspects of everyday life, or even with other fields of knowledge*” (Santos; Santos; Germano, 2024, p. 8).

Finally, these authors point out that while some studies did not explicitly mention culture in their titles, the discussions developed throughout their texts were situated within the cultural scope of physics teaching. This emphasizes the relevance of understanding physics teaching as part of a broader context, in which art, culture, and science interact with and complement each other. Continuing the investigation carried out by Santos, Santos, and Germano (2024), we expanded that study to 2023 and 2024, considering the same journal (CBEF), using the same search elements. The goal was to determine whether there was a trend of publications on these topics, since the results in Santos, Santos, and Germano (2024) showed an increasing number of published works in recent years, with 45.2% (14 of 31) occurring between 2020 and 2022. In our search, we identified four works that presented relations between science/physics and culture, of which three addressed cultural contexts and science (Gil-Perez; Vilches, 2023; Braga, 2024; Vaz et al., 2024), and one study addressed the context of science museums and interculturality (Alves-Brito; Nunes, 2024), demonstrating a continuity of published works on the topics in question. These studies presented different aspects of these intersections, including an emphasis on educating people for creativity, critical thinking, and an ability to understand and interact with the world they live in, as well as aspects related to teacher education. On this last topic, Galvão (2006, p. 50) argues that,

> *Looking again at school, the study says that a cosmopolitan teacher is more effective than one with a package of compartmentalized knowledge for understanding the world (Griffin, 1999). The term ‘cosmopolitan’ refers to the teacher who sees links between diverse fields, such as science, literature, mathematics, music, and language, who helps students give meaning to the huge set of stimuli they are subjected to each day. We need to have prospective teachers who do not remain structurally focused on pieces of the school curriculum or teaching approaches, but rather see the world around us as connective, as an amalgam of thoughts and actions, events, and artifacts that together make up the cultures and societies that we share.*

Galvao (2006) warns about the importance for the teacher to exceed the limits of a fragmented and compartmentalized curriculum. He proposes a connective and interdisciplinary approach, where the teacher not only “transmits” specific knowledge, but “builds” knowledge with students, creating more inclusive and transformative scenarios, with interdisciplinary intersections. In this context, the discipline "Art-Science-Culture and the Teaching of Physics" stands out; it is part of the teacher education program in physics at the Federal University of the Triângulo Mineiro, at Uberaba/MG. This discipline proposes a reflection on the didactic possibilities for future teachers, encouraging them to consider physics teaching from an interdisciplinary perspective, so as to overcome epistemological and methodological barriers, promoting broader, more integrated approaches to knowledge.

IV. Methodological design of the study

IV.1 Qualitative participatory research

This study adopts a qualitative approach (Bogdan; Biklen, 1994; Lüdke; André, 1986) through which we investigate and reflect on new forms of approaching physics teaching, especially in connection with initial teacher education processes. Qualitative research presupposes a keen eye for the analyzed object, perceiving and collecting as much information as possible for future analyses, that is, it allows in-depth understanding of the studied object (Cooper; Schindler, 2011).

This type of research differs from the so-called quantitative method in that it "*does not employ a statistical instrument as the basis of the analysis process. It does not aim to count or measure homogeneous units or categories*" (Richardson et al., 2015, p. 79). Therefore, this type of research has some peculiarities, such as: the environment in which it occurs; the researcher as the main instrument of investigation; strict correlation between the data in the contexts they were constructed in; the fact that a qualitative investigation is descriptive and interpretative; the processes are as important as the products; the interpretations are of an inductive nature; the meaning or meanings that people assign are more important than the generalization of results; and the knowledge construction process occurs through dialogue (Vilela 2003).

Through these elements, the qualitative approach can understand a social phenomenon in its context of origin, describing the complexity of a given problem, analyzing different variables, and pondering particularities of the behavior of the study participants (Richardson *et* al., 2015). In the present case, the qualitative study relies on a participatory research approach, which uses dialogue as a form of communication and data construction. Some authors argue that participatory research requires as a starting point understanding clearly that the participants are active partners in the construction of research data, that is, it contrasts with the idea that the latter are mere informants, acting only in the transmission of information. In this context, Faermam (2014, p. 50) argues that,

> *The idea that knowledge is collectively built points us to its own nature as incorporation of produced elements, their overcoming, and the creation of new ones. Accepting this conception implies understanding that knowledge is a historical and plural product, which originates from experience and is forged in the relationship between men and nature; this is a premise of participatory research.*

In our study, this scenario is decoded by the active participation of the pre-service teachers in the activities and actions throughout the discipline "Art-Science-Culture and Physics Teaching," in the physics teacher education program at the Federal University of Triângulo Mineiro at Uberaba, which we began to discuss in the next section.

IV.2 The discipline in question and the study participants

At this point, we find it is necessary to present the discipline in which the study was developed, as well as who the study participants are, both as contributing agents and in the knowledge construction process. The discipline "Art-Science-Culture and Physics Teaching" is part of a list of 21 elective courses in the field of physics teaching at the program in question, with a course load of 90 hours divided across 15 four-hour classroom meetings and 30 hours of out-of-class activities.

Each academic semester, the program offers three elective courses on physics teaching. The pre-service teachers must complete seven of these courses throughout their studies, specifically between the 3rd and 7th periods (the penultimate of the course). The students choose which disciplines to complete, and there are no prerequisites. This system affords future teachers curricular flexibility, that is, it allows them to shape their education and academic path, approaching topics of greater interest. In the case of the course "Art-Science-Culture and Physics Teaching," its syllabus has the following topics to be studied:

> *The science-art-culture relationships for physics teaching. Using films, theater, cartoons, music,* cordel*, comic strips, comic books, and other cultural productions as didactic strategies for teaching physics. Decoding and using different languages and social-linguistic codes. Contribution from different cultures in the relationships between art-science-culture and physics teaching* (Universidade Federal do Triângulo Mineiro, 2024, p. 124).

Therefore, among its goals, the discipline promotes integrated activities discussing the relationships between art, science, and culture in the context of physics teaching; stimulates the creation of didactic plans; encourages cultural enrichment activities; fosters collective and dynamic work; promotes scientific knowledge and encourages reflection on school culture; fosters students' intellectual autonomy, valuing the expression of their ideas and non-scientific knowledge, as well as reflection on teaching instruments to be used in basic education (Universidade Federal do Triângulo Mineiro, 2024).

Thus, 23 pre-service teachers (13 men and 10 women) enrolled in the discipline in the first academic semester of 2023 and participated in this study. This is a significant number of students in relation to the total in the program, which, by the end of 2023, had 75 enrolled students, according to data collected from its coordination office. Of the total participants, 43.5% were situated between the 3rd and 5th periods in the program, 26.1% between the 6th and 7th periods, and 30.4% in periods beyond the 7th, that is, outside the ideal profile for taking the course. This distribution of students at different points in the program is one of the peculiarities about elective courses, enabling a rich exchange of knowledge between them, as well as different educational experiences. To ensure the confidentiality and privacy of participants, they are denominated as Student 1, Student 2, […], Student 23.

IV.3 Methodological Paths of Reflection (MPR)

This research is situated in the context of teaching with research, developed in the classroom, and supported by theoretical foundations from the field of teaching. Thus, to investigate to what extent the intersection between art, science, and culture can contribute to physics teaching, we built an approach that we call "Methodological Paths of Reflection (MPR)." This approach combined different activities during the classes, such as: working with an initial questionnaire with the pre-service teachers; dialogical, participatory, and interactive classes; collectively designing and presenting didactic-pedagogical products; and think aloud protocols recorded in a final questionnaire. Thus, the following steps were conducted:

a) a preliminary survey and inquiry through an initial questionnaire – Knowing students' knowledge as they start in the discipline is valuable information for thinking about, preparing, and conducting discussions over their teacher education processes. Following Paulo Freire's ideas, in this context the student is not considered *tabula rasa*, lacking any knowledge, but someone active and immersed in social interactions;

b) Dialogical, participatory, interactive classes – Dialogue entered the agenda of discussions with the pre-service teachers, that is, effectively engaging them in discussing the contents to be addressed contributed significantly to the discussions between art, science, and culture, linked to these students' immediate everyday lives;

b) Collective designing and developing didactic-pedagogical products – This group action led students to reflect on some of the topics to be addressed, in addition to promoting teamwork in thinking about how to bring physics to basic education in dialogue with art and culture. In addition, when presenting their productions, the students practiced skills such as speaking in public, answering questions, and improvising in unexpected situations;

d) Think aloud protocols and records in a final questionnaire – Think aloud protocols were the step that resumed discussions held throughout the semester, and included listening to students' perceptions on the activities performed. The students formed a circle and were given the questionnaire they had initially completed. Based on their initial answers, they were invited to verbally express what they thought about those answers, and then they recorded their impressions in the final questionnaire.

IV.4 Forms of data organization and analysis

The research data were organized and analyzed using textual discourse analysis (TDA). TDA is an information analysis and organization method that aims to "*produce new* *insights into the studied phenomena*" (Moraes; Galiazzi, 2020, p. 7). In this analytical method, texts are deconstructed to establish relationships that lead to new findings – those that contribute to answering the research questions. TDA is a method that involves significant metamorphoses in how researchers conceive and approach their research objects, as well as in the course of analysis. This approach demands constantly reconstructing the comprehension of the writing process, which allows discovering new meanings in the writings, as well as creating new knowledge.

The researchers become active subjects, assuming authorship of their texts and manifesting their own voices. However, the research process is challenging, requiring coping with insecurity and uncertainty in a trajectory that is constantly under construction. TDA implies reading the analyzed material exhaustively and adopting gradual decision making. Despite the difficulties, this approach provides much freedom to create and express ideas, promoting a transformation of both researchers and the theories and practices that emerge from these analyses.

In TDA, "*the aim is to understand, reconstruct existing knowledge on the researched topics*" (Moraes; Galiazzi, 2020, p. 11); it is therefore a self-organized construction and comprehension process in which the researchers are situated in the interpretation of data. Thus, its corpus is essentially made up of text productions, and the process consists of three steps, namely unitarization, categorization, and metatext. These analysis steps provide a clear and systematic script for qualitative data analysis, allowing researchers to take a rigorous and reflective approach to interpreting the texts. Thus, the researchers also take on the role of authors of the texts resulting from the analysis, since theories, epistemologies, and personal methodologies directly influence their interpretation and the results from the research object.

Unitarization provides a solid foundation for further analysis, allowing the researchers to identify emerging patterns and topics in the material. During the exploration of the material, the focus is on identifying relevant units of meaning, providing deeper insights into the discourses present in the texts. Thus, unitarization uses selection or fragmentation to find in the study corpus elementary components that are relevant to the investigation. This involves the researcher's immersion in the data. Importantly, the unitarization process should bear in mind the study as a whole, and thus should not be excessively used (Moraes; Galiazzi, 2020). It is from unitarization that connections occur which support the construction of analysis categories.

In this study, unitarization is represented by reading all the material constructed throughout the discipline, and involves monitoring students in class, the proposed activities, and the initial and final interviews, held at the beginning and in the last class of the discipline, respectively. The units defined in this chaotic process advance toward categorization, that is, "*a process of constant comparison between the units defined in the initial analysis step, leading to clusters of similar elements*" (Moraes; Galiazzi, 2020, p. 22).

The categorization of data into initial, intermediate, and final categories challenges the researchers when generating binding arguments. For Moraes and Galiazzi (2016, p. 51-52), "*In* *this movement, the researcher, based on the partial arguments from each category, exercises explaining an argument that binds the whole together. This is then used to sew the different categories among themselves, expressing an understanding of the whole.*" The authors add that this process requires permanent and critical reflections based on partial products and complete and rigorous explanations as to meanings. This movement aims to group expressions and ideas that express similar meanings in relation to the studied phenomenon. In this study, the categorization was defined based on the data constructed throughout the discipline's training process.

As for the metatext, according to Kitzberger *et al.* (2022), this is a self-organized process that involves a recursive cycle of reading, rereading, and rewriting categories and meanings, culminating in the conclusion of the study. In the study at hand, the metatext derives from the analyses that form the categorization, that is, it reflects the final category created. According to Moraes and Galiazzi (2016, p. 104), the metatext reflects "*a written production, resulting from a textual discourse analysis, consisting of descriptions, interpretations and integrative arguments [...] based on which new explanations and insights are constructed and expressed*."

V. What did the study elucidate?

To reflect on the study's findings, we begin by presenting, in a descriptive way, the activities completed by the students, using records of images and discussions about them. Then we focus on the analytical reflections about the results, using textual discourse analysis (TDA).

V.1 Activities held in the discipline "Art-Science-Culture and Physics Teaching"

In this descriptive section we present the activities carried out throughout the discipline in question, which were not only based on playing activities, but also involved a theoretical basis, debates, and reflective constructions throughout 15 four-hour training meetings in the classroom. At the end of each meeting, a group-based systematization activity was proposed in which the students experienced what was discussed during that class. To enable experiences with methodological structuring that fostered more integrated teaching, and aiming to construct meanings for both student and teacher, we used the National Common Curriculum Base (BNCC), specifically the field Nature Sciences and its Technologies, to underpin the activities developed. The meetings were held in the first half of 2023 and had the following format:

a) Meeting 01: Presentation. This meeting aimed to introduce students to the discipline's purposes and collectively adjust the schedule of activities to be developed. This was an important step, as it allowed for a horizontal planning of activities, considering these aspects: student time availability to perform activities, forms of evaluation, group work planning, and final systematization. As for evaluation, it was diverse and sought to address different skills, that is, besides a written test. Thus, evaluation included writing reviews, group seminar presentation, and self-evaluation, in addition to completing the final questionnaire – think aloud protocols. A diagnostic questionnaire was also employed in this step, aiming to map students' expectations regarding the discipline, as well as their doubts and knowledge related to art, science, and culture topics;

b) Meeting 02: theoretical framework on the topic. We began discussions about the relationships between art, science, and culture from a historical perspective regarding the connections between these spheres of knowledge, showing the mutual contributions between them throughout history. We included ideas from different fields of knowledge in the debate, for example, constructions in perspective with Filippo Brunelleschi (1377-1446 1925), Leon Battista Alberti (1404 1973-1472), Leonardo da Vinci (1452-1519), and Galileo Galilei (1564-1642), as well as contributions by Brazilian scientists at the intersections between art, technology, and science, such as Abraham Palatnik (1928-2020) and Waldemar Cordeiro (1925-1973). The discussions were contextualized in our contemporary reality, using different resources (videos, texts, PowerPoint, and other means). As Araujo-Jorge (2007, n/p) points out with regard to Leonardo da Vinci (1452-1519), "*for a complete mind, study the art of science, study the science in art, learn to see, realize that everything is connected to everything*." This was the focus of discussions at this meeting;

c) Meeting 03: films and documentaries. From this meeting onwards, we began to discuss the use of different resources in the triad art-science-culture as physics teaching strategies. Therefore, this meeting was dedicated to discussions about films and documentaries. We began by presenting a historical landmark in audio-recording, with the 1895 footage by Auguste Marie Lumière and Louis Nicholas Lumière portraying a scene of French everyday life, "*L'Arrivée d'un train en Gare de La Ciotat*." Based on references on the topic, various possibilities for innovating physics teaching were discussed, particularly through the use of films and documentaries. This provided a fresh perspective on concept teaching (Oliveira, 2006; Mossmann and Villas-Boas, 2012). In addition, we discussed excerpts of various films with the students. For example: *Harry* Potter (2010) and the idea of an invisibility cover; *Angels and Demons (*2009) and the notion of antimatter*; Avatar* (2009) and the Meissner effect, regarding superconductors*; Dark Knight* (2008)*; Five Days to Midnight* (2004) and notions of restricted relativity; and excerpts from documentaries and TV news stories;

d) Meeting 04: Comic strips, comic books and editorial cartoons. At this meeting we held a workshop where the students made various comic strips, comic books, and scientific cartoons based on a previous theoretical discussion. This allowed students to dialogue with physics concepts based on different humorous text genres, as well as to practice verbal, non-verbal, and mixed language using written text and images. Despite their specificities, comic strips, comic books, and cartoons in general portray current and everyday issues, sometimes critically. Connected to scientific aspects, this production allows presenting concepts and contents in a contextualized and innovative way. As Caruso and Silveira point out (2009, p. 233), creating comics and comic strips can "*teach students how to build a narrative, imagining* *and creating what is implied between a frame and the next in the story sequence. They therefore contribute to developing language itself, the power of synthesis, creativity, and important concepts*.” The students were shown different resources to make comic strips, comic books, and editorial cartoons, such as: *Strip Generator, Super Hero Squad, StoryboardThat, Make Belief Comix, Canva,* among others;

e) Meeting 05: Literature and *Cordel*. At this meeting, we held a discussion about the use of *cordel* literature as a physics teaching resource. As Barbosa et al. (2011, p. 162) point out, “Cordel *is classified as as form of popular printed literature, and in the first decades of the 20th century it contributed significantly to the literacy of people in the Northeast region*.” Other authors add that, when addressing aspects of history, folklore, art, and music, *cordel* allows “*people with little formal education to actively engage in poetry, history, and information in general*” (Silva; Ribeiro, 2012, p. 235). In addition, creating *cordéis* is an exercise that fosters students’ creative and critical development. However, it is hardly ever employed in Brazilian schools, particularly in regions beyond Brazil’s northeast. Precisely in this atmosphere we proposed for students to create *cordéis* about scientific subjects (Fig. 1) at this meeting, so that the future teachers could have new horizons for physics teaching and science popularization (Zanetic, 2006b).

Fig. 1 – Cordéis about scientific subjects created by the students and then hung on a string for display on the whiteboard. Source: the authors (2023).

f) Meeting 06: Music and Podcast. "*Popular culture makes you think of Capoeira, a samba song by Noel or a tango song by Gardel. Yet, culture is hardly ever linked to Godel's theorem or to Maxwell's equations"* (Zanetic, 1989, p. 146). This was the focus of discussions at the sixth meeting, in which we addressed the use of music and podcasting as a physics teaching strategy. Such discussions are in line with official documents, which indicate that approaching "physics as part of contemporary culture certainly opens a significant interface between physics knowledge and social life" (Brazil, 2002, p. 39). This is the context in which we proposed for students to analyze lyrics of Brazilian popular songs as a didactic-methodological resource (Nascimento, 2012), that is, songs like: *Outras Frequências*, written by Humberto Gessinger and interpreted by the band Engenheiros do Hawaii; *O Segundo Sol*, written and interpreted by Nando Reis; *Queremos Saber*, by Gilberto Gil; among others. Discussions about podcasting were added, since podcasts are broadly disseminated nowadays.

g) Meeting 07: Theater. Different official documents have suggested that "*in physics classes we should seek new and different forms of physics knowledge*, *from writing to body and artistic language*s" (Brazil, 2002, p. 84). Throughout this meeting we presented and discussed possibilities for the future teachers regarding the use of theater as a physics teaching strategy. Based on texts discussing the subject, such as Napolitano (2013), Nory and Zanetic (2005), Henrique and Colombo Junior (2011), Mirabeau et al. (2011), among others, various theoretical and classroom-based possibilities of using theater in physics teaching were presented.

h) Meeting 08: Stop motion with modeling clay. Stop motion animation has been growing in educational contexts in recent years, particularly in the context of nature sciences (Amorim, 2015; Oliveira, 2022). This technique involves the frame-by-frame recording of objects in different positions, thus telling a story, explaining a concept or a theory, for example, the so-called storyboards. The frames are individually photographed and animated using video editing software, thus bringing the story to life. As Amorim (2015, p. 2) points out, "*using animation allows creating a relaxed environment that draws students to actively participate in the class, while also stimulating skills like creativity and concentration, since it's a process that requires patience and discipline*," which were experienced during this meeting and throughout the presentation of the students' productions (Fig. 2).

I) Meeting 09: Gamification and simulations. In this meeting, aspects of digital culture and the use of games were addressed, particularly gamification and simulations, as didactic strategies for physics teaching (Nascimento; Nascimento, 2018). Gamification is a resource that aims to engage and involve students emotionally, using structures from games. The purpose of using this resource is to achieve a state known as flow – that is, intense concentration on the task at hand, driven by strong engagement and intrinsic motivation in the search for solutions to problems (Csikszentmihalyi, 1990). These aspects were perceived throughout the activities with the students.

Fig. 2 – Students creating scientific stop motion using modeling clay and low-cost materials. Source: the authors (2023).

j) Meeting 10: Preparation and discussions with the groups. We reserved this meeting to discuss the preparation of the activities to be presented in the classroom, in the form of a teacher training seminar-class. Thus, in groups, the students were to choose one of the strategies studied in the previous meetings, develop a lesson plan, and create a class designed for a high-school grade, lasting 100 minutes, followed by its presentation at the university (in the discipline) and discussions with the teacher and peers.

l) Meetings 11 to 15: The discipline’s final meetings were reserved for the group presentations, which were delivered as a lesson plan describing in detail the actions that were planned. These classes might include activities for their peers. The students were divided into four groups, and a meeting was scheduled for each presentation. The resources (topics/content) chosen for the presentations were: theater (kinematics); film (Newton’s laws); gamification (astronomy/creation of the game UNO Solar); and Music (Doppler effect). The final meeting was reserved for concluding the discipline, students’ feedback, and the think aloud protocols, with records in a final questionnaire that also fostered the analyses presented in the next section.

V.2 Analytical reflections on the research data

The following table (Table 1) results from the analyses of the whole study corpus, particularly the initial and final questionnaires, which included questions such as: What do you expect to study in this discipline? Do you believe that art, science, and culture are important for physics teacher education? Why? What art manifestations (film, theater, circus, etc.) do you consider most feasible for teaching physics concepts? In your view, can the use of cultural spaces and/or artistic languages benefit physics teacher education? Can integrating art, culture, and physics be important in physics teacher education? Why? Have you ever had any experience in arts (theater, film, etc.) in your trajectory as a student? With what art form(s)? What are your expectations for this discipline? The questions in both questionnaires were the same, except for the verb tenses used in them.

After organizing and analyzing the data, we initially identified eight categories. However, given the continuous and critical reflections enabled by textual discourse analysis, we re-read and recreated the categories and their meanings successively. This process allowed for a progressive reduction of the initial categories, culminating in a final category, for which our reflections are presented through the metatext. To make the categorization process clearer, we used letters to represent each category, and numbers to specify the number of units of meaning in each of them.

Table 1 – Process of categorization and creation of the metatext with analyses and reflections

Initial category	**Initial category arguments**	**Intermediate Category**	**Intermediate category arguments**	**Final Category (Metatext)**
A. Students' expectations and worries regarding the subject of ACS in PT	- Having access to new methodologies for PT (8) - Expanding physics studies based on its relationship with other disciplines (1)	C. (A +B) = (9+ 5) = 14 C. Exploring the subject of ACS in PT provides new didactic tools for classroom teaching practice	- Physics is strongly present in people's daily lives; however, the way it has been approached in schools does not arouse students' interest. In this context, the relations between ACS can contribute significantly, provided that it considers teacher education.	M = (C + F + I+ L) = (14 + 42 21+31+108) = M. The relations between ACS in fostering more humane, understandable, and meaningful PT for students in their daily lives.
B. Importance of the relations between ACS in and for physics teacher education	- Innovating PT so that students realize its presence and importance in their daily context (5)			
D. Art and culture manifestations that can contribute to teaching physics concepts	- Cinema and films are more feasible means of contributing to PT (17) - This depends significantly on students' goals and age group,	F. (D +E) = (19 + 23) = 42 F. Teachers can use many arts resources to teach	- The arts provide a wide range of possibilities for PT, such as films, since concepts can be easier to understand	

	therefore, some manifestations can make more sense to some than to others in teaching scientific concepts (2)	physics to students, depending on their education level.	visually; music, with its reflection, theater, for its lighter thematic approach that can arouse viewers' interest in further learning.	
E. Art and culture play an important role in physics teacher education.	- The component of these approaches captures students' attention, making the content more interesting. (9) - Expanding knowledge of different areas can facilitate teachers' didactics - by connecting interdisciplinary concepts (14)			
G. Achieving the discipline goals from students' perspective.	- Easy-to-access content and references for conducting the activities (6) - It is also necessary to dialogue with other tools, such as technological ones, to expand the scope of the discipline. (2)	I. (G +H) = (8+13 21) =. The didactic resources approached can help students experiment in school through pedagogical plans such as PIBID. However, facilities are insufficient for them to experience these methodological resources.	- The discipline ACS for PT allowed experimentation in various artistic and cultural tools that contribute to teaching. Educational plans, such as PIBID, are great spaces for students to put these plans into practice, but we still found that more infrastructure is necessary for these teacher education practices.	
H. Practices conducted out of the classroom throughout the discipline.	- PIBID allowed experimenting with films/videos and gamification games. (6) - Out of the scope of the discipline, there was no opportunity to put what was learned into practice. (7)			
J. Methodologies used in the discipline, what	- Film, music, comics, theater, gamification and stop motion are	L. (J+K) = (17+14) = 31 Resources such as	- Using all the methodological resources presented in the discipline	

could or could not be used in the classroom	considered the most fun and easiest to develop. (8) - Because it is regional and very specific, *cordel* literature was more difficult to use (9)	films, music, comic strips, theater, gamification, and stop motion facilitate students' learning process, making physics classes more attractive and less conventional.	ACS for PT, it was found that films, music, comics, theater, gamification, and stop motion are real possibilities to be used in the classroom to bridge the gap between theoretical and practical learning in physics teaching.	
K. Art and culture promote a more attractive class for students.	- Art and culture facilitate the teaching/learning process, departing from conventional classes. (6) - Physics as a science has highly conceptual contents that students can view more easily through art and culture. (8)			

* PIBID means: Institutional Teaching Initiation Scholarship Program. ACS means: Art, Science and Culture

Source: the authors, based on the study by Calixto (2019)

By analyzing the research corpus, we found 108 units of meanings (Table 1), which culminated in the creation of a metatext $(\phi) - category\ M$. The dynamics for this can be interpreted as the sum of the analysis categories from A to L, summarized as follows:

$$\sum_{A \to L}^{Cat.} = Cat.A + [\ldots] + Cat.L = Cat.M \quad \rightarrow \quad \sum_{A \to L}^{Cat.} = 9 + [\ldots] + 31 = 108\ units$$

$$\sum_{A \to L}^{Cat.} = \phi = \boldsymbol{Metatext}$$

These units of meaning are therefore representative of an initial analysis of the data constructed with the participants, especially based on the initial and final questionnaires. In this process, as the initial categories were combined into intermediate categories, a final category emerged which represents the metatext: "*The relationships between ACS in promoting more humane and comprehensible PT that makes sense to students in their daily lives,*" which we present below.

V.3 Metatext: The relationships between ACS in promoting a more humane and comprehensible PT that makes sense to students in their daily lives

Initially in our discussions on the relationships between ACS in promoting a more humane and comprehensible physics teaching (PT), we highlight students' position in understanding this aspect based on the strategies studied. Student 1, for example, argued that in a classroom context, he "*would bring* [to his students] *films, songs, comic strips, theater, and stop motion. Because I believe these contents are more fun and easier to develop"* (student 1*)*. On the other hand, the student also shows insecurity regarding other contents: "*I wouldn't bring cordel works or literature. Because I believe cordel is regional and very specific, and literature as it is less remarkable"* (Student 1). Interestingly, as shown in this statement, regional differences can influence methodological choices in teaching practice, while other possibilities can make the pre-service teacher more comfortable to develop his practice.

The reflection of Student 1 on using *cordel* contributes to the reflection of Barbosa et al. (2011, p. 166) in which they say that while this format has an interesting didactic potential for physics teaching, *"cordel is little used in the classroom*." This finding reinforces the relevance of integrating regional culture activities into the training process, encouraging future teachers to recognize the pedagogical value of these methodological possibilities. Throughout the discipline, the urgency to discuss and implement innovative didactic strategies in the training of future physics teachers became evident, as few students mentioned to have studied art and culture topics in promoting teaching at the university. On this regard, Student 5 mentioned that "*there should be more disciplines like this because most teachers even from college struggle to transmit their content, and this discipline can play a part in this regard"* (Student 5*)*. This reminds us of Tardif's (2005) observation when he notes that teaching knowledge must be "plural, formed by a more or less coherent amalgam of knowledge derived from professional training combined with subject matter, curricular, and experiential knowledge" (Tardif, 2005, p. 36).

The analyzed data show that, for the research participants, this plural knowledge was decoded into using different artistic and cultural resources: films and documentaries; comic strips, comic books, and cartoons; *cordel* literature; music and podcasting; theater; stop motion; gamification and simulation. This scenario fostered relevant discussions among students about the importance of new methodologies in teacher training. Additionally, the importance of this preparation was noted for its potential to innovate physics teaching in basic education, especially by using these resources as strategies to change the negative image rooted in the educational context that physics is boring, inaccessible, and decontextualized from students' everyday life.

Based on Philippe Perrenoud's ideas, Shinomiya and Ricardo (2012, p. 9) argue about the need to "*adapt taught content and learning strategies to the school's educational approach*." This context reveals the importance of providing teacher training on the use of ACS in PT with interdisciplinary resources that foster students' creativity, curiosity, and critical thinking, since this promotes more meaningful and engaging learning. However, in addition to the teacher education process, other issues emerge as significant limitations in this innovation process—for example, the curriculum, the number of hours dedicated to physics, and school infrastructure and resources were among the factors mentioned by the students during the teacher education meetings. These notes corroborate Moreira (2017), when he reflects on the challenges of physics teaching in contemporary education, and with Rosa and Rosa (2005), who presented teachers' views about defining and choosing physics topics, given the discipline's reduced weekly courseload. Moreira (2017) argues that the small number of physics classes in high school is something to be addressed in today's school, and this should not be concealed, but rather publicized in all its implications in terms of policy, teacher education, and education for citizenship. This is a challenge that, in addition to the political issues that govern the education system, may also be in the context of teaching as what we call mediating-teaching. In the contextualization process, the goal is to maximize class discussions centered on what students already know and their experiential context, as scientific education should *"ensure for individuals a better relationship with the world they live in"* (Pietrocola, 1999, p. 225).

Additionally, mediating-teaching leads students to new educational horizons, within a process of criticism of what is learned beyond the classroom. It involves laying teaching bare to encourage reflection on its practice, moving away from the mere transmission of knowledge. In addition, we agree with Moreira (2017) that political issues are fundamental to these reflections – specifically, the weekly physics courseload in high school has been drastically reduced over the past decades, now limited to around two hours or less, and 'approaching zero if physics is merged into a single "Nature Sciences" discipline. *It is necessary to struggle for more classes and for the non-merging of physics into this 'new discipline.' The interfaces between disciplines are important, and so are interdisciplinary or multidisciplinary activities, but "merging" disciplines such as physics, chemistry, and biology into one is a pedagogical absurdity. They are important"* (Moreira, 2017, p. 12).

For the pre-service teachers, such difficulties restrict the inclusion of more dynamic and exploratory activities, often leading teachers to adopt traditional and content-oriented approaches to the detriment of more participatory and interactive methods. On the other hand, despite the classroom application difficulties raised by the pre-service teachers, they all agreed that the discipline "Art-Science-Culture and Physics Teaching" was highly valuable for their professional training, and they find it feasible to bring most of the presented methodologies to the classroom, integrating them to their future teaching practice. Colombo Junior and Ovigli (2018) highlight the contributions of integrative disciplines such as this in teacher education, emphasizing that:

> *For the training of pre-service teachers, [this is] [...] an opportunity to reflect, still in initial teacher education, on new ways of teaching physics, provoking a desire to innovate in teaching practice, paying attention to their own professional development. It can even contribute for students to see physics present in everyday life, the product*

> *of human construction, and not the work of "isolated geniuses"* (Colombo Junior; Ovigli, 2018, p. 116).

Therefore, proposing new perspectives and discussing different possibilities to teach physics contents becomes an opportunity for teachers in training to gain a theoretical-methodological framework that fosters innovation in their classroom practice, bringing classroom physics closer to students' everyday life, and building new school knowledge. The data analysis also points to the importance of pedagogical practices in teacher training, since physics has the potential to become a more attractive discipline, leading students to build knowledge in a more meaningful way.

The analyses showed pre-service teachers' high expectations about learning to dialogue on new methodological possibilities, examining different didactic possibilities in their initial teacher education. This fact was synthesized in this excerpt by Student 17, saying that he sees good prospects in teacher education as he finds "*new ways of integrating arts, sciences, and culture in the classroom, aiming at better education for students. To understand how much I can use art to teach physics and different modes of teaching"* (Student 17). The pre-service teachers also said they recognized that besides making PT more accessible and interesting, integrating these areas can also bring "*student and teacher closer together through an artistic or cultural element*" (Student 11), which is highly desirable in the social teacher-student interactions.

Despite this perception, we also observed a persistent gap in teacher education, raising obstacles for the dissemination and production of new knowledge in physics teaching, that is, the availability of didactic materials that foster innovations in the school context. At various points throughout the meetings, students complained about finding many ideas for teaching practice innovation based on the art-science-culture intersections, but only in scientific papers and journals, with manuals and textbooks offering much less than expected as regards these ideas. This is an interesting finding that opens an important path for reflection, that is, to what extent have studies on physics teaching actually contributed to better school teaching and new approaches in the textbooks given to teachers?

This concern leads us to reflect on what Krasilchik and Marandino (2004, p. 30) pointed out, namely that "*the complexity and quality of socially produced knowledge bring huge challenges for understanding it. In school education, the selection between knowledge and cultural materials aims to make them effectively transmissible and assimilable."* In addition to the problem presented, we noticed that the search for new possibilities in physics teaching has been constant for the pre-service teachers participating in the study, that is, in their statements, they are seeking to innovate physics teaching, so that basic education students can see it in their own daily lives. Therefore, every stage of the future teachers' education involves harnessing the human potential, something that is very present in our teacher education actions. Importantly, however, the pre-service teachers showed concern about the presented resources' effectiveness, that is, at various points, different students argued that a class cannot be just entertainment, but should observe the rigor required for scientific concepts and teaching experiences that can generate significant learning.

This highlights their care not to devalue the role of acquiring scientific concepts, historically built and validated, to the detriment of "learning to learn", by itself, detached from the scientific and epistemological rigor that guides the construction of science. Duarte (2001) highlights the motto "learning to learn" and the values it represents. The author highlights the overvaluation of knowledge built by oneself, in contrast to knowledge built by another, a fact that may tend to the negation or even devaluation of teachers' work and the act of teaching. Therefore, in this scenario, the school's responsibility to teach is diminished or even removed, benefiting the more privileged layers of society and a neoliberal system (Saviani; Duarte, 2012; Buzzo; Treviso, 2016). A valuational approach to scientific knowledge construction method and processes in relation to the products of that construction, that is, the knowledge validated by the scientific community can represent a deformation in the act of teaching and in teachers' work, these factors should be addressed by educational systems (Duarte, 2001).

Pietrocola (1999) criticizes the constructivist movement as a guideline for knowledge construction, challenging the overvaluation of individual constructions to the detriment of the ontological dimension of scientific knowledge. Based on a review of studies, the author argues that the target of his criticism is not "*the constructivist movement as a whole, but the tendency to generalize and radicalize the metaphor of doing associated with a subject's action, to the detriment of other metaphors such as discovering and finding, more associated with the object of knowledge*" (Pietrocola, 1999, p. 214), which is supposedly related to the epistemological foundations of constructivist discourse. Matthews (1994a, p.147) also reflects on these aspects and says that "*risky foundations are revived*," based on understanding knowledge that is isolated and conducted through direct observation and learning by discovery, far from traditional didacticism's epistemological and ontological commitments (Laburu, Carvalho and Batista, 2001). Thus, Matthews (1992, *apud* Lemant, 1997, p. 42) argues that his criticism is focused on the idea that "*constructivism maintains the Aristotelian-empiricist epistemological paradigm, centered on the subject, generalized, and common sense; by correctly pointing out a major error in empiricist assumptions, he then oscillates to a relativist epistemology without abandoning the paradigm itself*." In other words, Matthews (1994b, p. 81) emphasizes that, "*epistemologically, constructivism is the old and famous empiricist wolf in contemporary sheep clothing. To change the metaphor, it is the empiricist wine, so criticized by constructivists, served in new bottles*."

This fact clearly shows the training awareness of future teachers, giving us hope in quality education with responsibility. As the esteemed professor João Zanetic (1943–2024, in memoriam) advocated, taught, and extensively argued, his understanding of physics as culture was not an attempt to replace a formalistic approach with a romanticized one. Rather, he sought to "provide cultural substance for these calculations, so that these formulas gain scientific reality and people can understand the connection between physics and intellectual and social life in general" (Zanetic, 1989, p. 8).

Among the methodological possibilities presented in the discipline, the ones that most aroused the students' interest in using them in the classroom were: films, as visual concepts can be more easily understood; music, with its potential for building reflection; and theater, due to its lighter thematic approach, which can arouse viewers' interest in learning further. This was an interesting aspect, since the pre-service teachers showed that they were open to thinking about innovation in the classroom based on the relationships between art, science, and culture. Student 8, for example, showed an important reflection in this regard by saying that: "*before the discipline started, I'd been thinking a lot about different teaching methods. When I started in the subject, I felt really inspired to become a teacher, especially as I had contact with other methodologies"* (Student 8). This account and others of the same nature show the importance of rethinking initial teacher education, that is, the nuances that can provide differentiated training, the motivational impacts of hope and reaffirmation of a career choice, these factors were presented through new ways of teaching physics.

As the analyses draw to a close, it is worth pointing out that at different points the pre-service teachers referred to the importance of interdisciplinary projects and experimenting in school daily life, especially in physics teaching. Thus, for them, the approaches they were shown allow forming the tripod experimentation-interdisciplinarity-innovation, i.e., it is possible to work with experiments based on theater, with interdisciplinary concepts in comic strips and cartoons, among so many other possibilities. Thus, it was argued that these approaches not only facilitate teaching theoretical concepts, but they also play a crucial role in creating meaningful links and building solid references with their students. These factors corroborate the ideas of Pereira and Praça (2023, p. 2) that "*the encounter between science and art can enrich students' education, since both instigate curiosity, human critical thinking, and experimentation*".

Based on the reflections above, we can say that the intersections between art, science, and culture provide a fertile ground for thinking about new possibilities for physics teaching, in addition to being an important way to reflect on teachers' initial education, by providing foundations for any innovation process in basic education. This is critical for overcoming the distortions rooted in society which portray physics as boring and decontextualized from society. We conclude by agreeing with Massarani, Moreira, and Almeida (2006, p. 10) that art and science, "*both feed on the same humus, human curiosity, creativity, the desire to experience. Both are shaped by their history and context. Both are immersed in culture, but they imagine and act upon the world with different perspectives, goals, and means*."

VI. Limitations and final reflections on the study

"Reinventive"!

Reinventing is a verb. A verb is always in motion – just like teacher education processes and teaching. This study, too, was conducted in constant motion, and through a deep dive into empirical analysis, new discoveries emerged. “Reinventive” is someone who refuses to settle, who challenges the given and seeks to innovate. The “reinventive-teacher” is always after new ways of teaching and learning, they face the contemporary challenges of education and deal with the adversities that are daily imposed.

After the exercise of analyzing the empirical material constructed in the study, the pre-service teachers’ accounts show that integrating art and culture into physics teaching can provide more accessible and relevant teaching by connecting scientific concepts with students’ daily lives. By reflecting on the impact of this interdisciplinarity, it was clear that the pre-service teachers realized the importance of creating a pedagogical environment that goes beyond curricular rigidity, allowing knowledge to be experienced more significantly. Even in the face of structural and curricular difficulties, the participants were unanimous in considering that it is worth investing in innovative methodologies, such as the use of films, music, theater, and other practices to create classes that awaken students' interest and transform how physics is perceived.

Thus, as Pocay (2014) points out, it is essential to explain to students the purpose of activities, the role they will play in them, and the proper use of the materials provided. This approach aims to minimize any potential sense of strangeness that may arise from using less conventional elements, such as music, in mediating pedagogical practice. However, this author also warns about the possibility that this novelty generates insecurity or even a lack of interest on the part of the students. This observation highlights a crucial point for teaching: the importance of preparing students for new approaches, so that they feel engaged and confident to explore innovative methodologies. Despite the initial challenges, including elements such as art and culture in the pedagogical process can create significant opportunities to enrich students’ learning experience, making it more dynamic and relevant. Thus, it is the teacher’s responsibility not only to plan the introduction of such resources, but also to create a welcoming and conducive environment where students feel motivated to participate, overcoming any resistance or discomfort.

Thus, it became clear throughout the study that including innovative methodological practices within teacher training has the potential to bring physics closer to daily life, making classes more interesting and interactive by valuing not only the content, but also the teaching-learning experience, using methodologies that foster students’ autonomy, creativity, and active participation. Physics, as well as art, science, and culture, is part of the same society in which “*artistic and scientific practices are two sides of the human action and thought, complementary faces, but mediated by tensions and disagreements, which can foster innovation, mutual enrichment, and humanistic affirmation*” (Massarani; Moreira; Almeida, 2006, p. 10). Finally, we conclude that this study underscores the need to rethink physics teacher education beyond the traditional perspectives on teaching, by adopting more flexible and creative approaches, such as integrating art, science, and culture in teacher education processes. Experiences, experimenting, discussions, and connections are essential for building future "reinventive" teachers who know how to inspire and engage their students, making physics a living, engaging, and transformative discipline for all.

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