ALEXANDRIA

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The convergence between Physics and the Arts: motivations and challenges for planning interdisciplinary practices

A aproximação entre a Física e as Artes: motivações e desafios para o planejamento de práticas interdisciplinares

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Abstract: This study investigates the motivations and challenges that permeate collaborative planning and the development of activities involving Physics and Art, based on a continuing professional development coursebuilt from an interdisciplinary, collaborative, and non-hierarchical perspective. Interdisciplinarity is understood as a creative process in which teachers interconnect different forms of knowledge to address relevant problems within the school context. Drawing on Design-Based Research, participants' experiences were analyzed to identify elements that facilitated and hindered integration between the areas. The results highlight the potential of collective work to encourage group planning and the sharing of knowledge, fostering meaningful interdisciplinary proposals. However, difficulties also emerged, particularly in the organization and implementation of these practices. The analysis underscores the importance of dialogue around themes central to interdisciplinarity and the creation of spaces for interaction, which strengthen both collaborative work and the connections between disciplines such as Physics and Arts.

Keywords: interdisciplinarity; Physics and Art; collaborative work; teacher education; design-based research.

Resumo: Este trabalho investiga quais motivações e desafios perpassam o planejamento colaborativo e o desenvolvimento de atividades envolvendo Física e Arte, a partir de um curso de formação permanente desenvolvido em perspectiva interdisciplinar, colaborativa e não hierárquica. A interdisciplinaridade é compreendida como um processo criativo, no qual docentes interligam diferentes saberes para abordar problemas relevantes no contexto escolar. Com base na Pesquisa Baseada em Design, foram analisadas as experiências dos participantes para identificar elementos que favoreceram e dificultaram a integração entre as áreas. Os resultados evidenciam o potencial do trabalho coletivo para incentivar o planejamento em grupo e o compartilhamento de saberes, construindo propostas interdisciplinares significativas. Entretanto, também emergiram dificuldades, sobretudo na organização e implementação dessas práticas. A análise ressalta a importância do diálogo sobre temas centrais à interdisciplinaridade e da criação de espaços de convívio, que

fortalecem tanto o trabalho colaborativo quanto os vínculos entre disciplinas como Física e Artes.

Palavras-chave: interdisciplinaridade; Física e Artes; trabalho colaborativo; formação docente; pesquisa baseada em design.

Introduction

In this article, we aim to explore interdisciplinarity as a creative process in which teachers, by using their knowledge dialogically, can interconnect different forms of understanding to address relevant issues within the school context. Thus, interdisciplinarity enables the construction of connections among diverse fields of knowledge, enriching the educational process and providing a more holistic view of the subjects addressed. This approach aligns with the ideas of Fourez et al. (1994), who propose interdisciplinary models to deal with situations that require the integration of diverse knowledge in order to overcome everyday challenges.

The segmentation of disciplines emerged as a way to organize and facilitate the understanding of specific phenomena, since it is easier to comprehend smaller parts before understanding the whole. However, the integration among different fields of knowledge has gradually become less viable, making it increasingly difficult to grasp phenomena in their complexity. At this point, the content-centered approach loses its relevance in students' lives (Araújo, 2014). Possibly, the lack of connection with real-world phenomena may be linked to the supposed demands of society and to the growing range of skills expected from our students.

Regarding interdisciplinarity, we seek to explore the connections between Physics and Art, considering a differentiated perspective on the cultural issues present in both fields. Fourez et al. (2002, p. 29) point out that partitioned knowledge, shaped by disciplinary traditions and resistances, provides "fractions of knowledge for fractions of time". The author further argues that the learner's autonomy enables them to negotiate their decisions and to communicate them with a certain degree of mastery and responsibility in everyday situations (Fourez et al., 1994). This context, which relates to the challenges faced in Physics education and to the lack of association between Physics and culture, is discussed in the works of Zanetic (1989). The author advocates that Physics should be integrated into the cultural education of citizens, regardless of their personal preferences or their diverse academic and professional goals, thus reaching students who do not feel motivated to learn Physics through traditional methods.

On the other hand, Art Education does not face difficulties in associating curricular content with culture, since Art is already recognized as a cultural source. However, several conceptions of Art teaching have emerged over the years. In their exploratory research, Silva and Araújo (2007) highlight four main approaches: (i) Art teaching as technique; (ii) Art teaching as expression; (iii) Art teaching as activity; and (iv) Art teaching as knowledge.

i) Art Teaching as Technique: Art teaching as a tool to support other disciplines and to prepare students for the job market, yet without contextualizing Art itself.

ii) Art Teaching as Expression: Emphasizes the free production of drawings and paintings and includes visits to museums and theaters, but without prior planning or structured guidance from the teacher.

iii) Art Teaching as Activity: Involves artistic activities without focusing on Art curricular content, such as school singing or classroom decorations for commemorative dates, without a structured teaching framework.

iv) Art Teaching as Knowledge: Explores Art as a field of knowledge, grounded in interculturalism, interdisciplinarity, and the learning of artistic knowledge through the interrelation of making, reading, and contextualizing Art.

In this study, we adopt the term Art in the singular, in line with the concept of a field of knowledge connected to history and human development (Figueiredo & González, 2019). In the school context, however, we use the term Arts in the plural, in accordance with the Lei de Diretrizes e Bases da Educação Nacional (LDB, Law of Guidelines and Bases of National Education) (Brasil, 1996) and the Base NacionalComum Curricular (BNCC, National Common Core Curriculum) (Brasil, 2018). These legal frameworks define the curricular area of Arts as encompassing different forms of expression, such as Visual Arts, Music, Dance, and Theater. Considering that the teacher education program analyzed in this study primarily focused on visual works and productions, we highlight Visual Arts as the predominant axis, while maintaining the broader concept of Art as a field of knowledge. Accordingly, we seek to ensure terminological clarity throughout the text by distinguishing Art (as a cultural and historical field), Arts (as a school subject), and Visual Arts (as the specific focus of the course).

In this regard, in seeking an articulation between culture and knowledge within the classroom, a promising alternative would be to foster the integration of Science and Arts as forms of knowledge in the school context. Although these two fields may seem distant at first glance, the relationships established between them can lead to

enriching practices in education. Our premises consider the teaching of Arts as a field of knowledge and Scientific Literacy from a cultural and social perspective, thereby seeking an integration between these domains to advance the desired interdisciplinary initiatives. As Zanetic (1989, p. 104) argues:

> Since discussions in education so often refer to interdisciplinarity, integrated science teaching, and other similar terms, why not consider integration with other branches of knowledge, with other ways of speaking about the world, and with the world itself?

Although Zanetic's work dates back to the 1980s, Martin (2019) revisits these discussions by demonstrating that the need to integrate Science and culture remains relevant today, particularly in light of new social and educational demands. This dialogue highlights that the ideas proposed by Zanetic (1989) continue to inspire contemporary debates on the cultural role of Science and its connections with Art within the school environment.

The integration between Science and the Arts allows for an expansion of the boundaries of knowledge, valuing both creativity and critical analysis. In this regard, Benedicto (2021) argues that to consider Art and Science as forms of culture is to humanize them and to insert them within the political and social intersections of our society. By bringing these areas closer together, students are encouraged to view the world in a broader and more connected way, fostering more meaningful learning. The union between Scientific Literacy and artistic understanding offers a fertile path for the development of both cognitive and affective competences, strengthening the dialogue between different forms of expression and thought. Along these lines, Figueira-Oliveira et al. (2018) emphasize that the integration of Science and Art constitutes an essential pedagogical competence for teacher education, as it enhances teachers' critical and creative capacities in addressing the challenges of contemporary education. Thus, interdisciplinary initiatives become more robust, enabling an education that not only shapes but also transforms one's view of the world.

Connections between Physics and Arts in Teacher Education

In recent years, Brazilian education has undergone numerous transformations that have significantly affected teacher education. These changes are shaped by historical processes and by the interests of contemporary society. As discussed by Leite et al. (2018), social transformations have always demanded new directions in

teacher education, and this will continue to be the case. The authors emphasize that one of the main challenges is to prepare professionals who can meet the multiple demands of the educational context, especially in schools.

To address the challenges within the educational field, this study focuses on the continuing professional development of teachers as an organic process, taking into account the demands and challenges of initial teacher education. One of the main challenges is the gap between the knowledge acquired during initial teacher education and the competencies required in teaching practice, as well as the distance between teacher education institutions and the new cultural dynamics and social demands present in school contexts (Lisita et al., 2001). There is also a need for teachers to master both subject-matter and pedagogical knowledge in an interdisciplinary way, appropriate to the different stages of human development (Brasil, 2015). In this regard, Figueira-Oliveira et al. (2018) emphasize that the articulation between Science and Art can be understood as a central pedagogical competence for teacher education, as it supports the reconstruction of knowledge and the response to complex school demands through integrated practices.

As Leonel (2015) argues, overcoming these challenges requires investments in public policies that value the teaching profession and ensure adequate conditions for both the preparation and the professional practice of teachers. Among these conditions, it is essential to guarantee time for research and planning, as well as to provide continuing education courses that foster dialogue and collaborative planning among teachers from different fields, such as Physics and the Arts. This proposal aims to address the demands for interdisciplinarity and integrated practices, overcoming curricular fragmentation and promoting teaching that respects the specificities of each discipline (Leite et al., 2018).

The challenges faced in teacher education affect both initial teacher education institutions and those focused on continuing professional development (Leonel, 2015). In this regard, the Ministry of Education (MEC), in partnership with higher education institutions and with state and municipal education departments, has implemented several initiatives within the scope of both initial teacher education and continuing professional development for teachers. However, as Leonel (2015) points out, these programs often structure their methodologies around the simple transmission of knowledge, without taking into account the specific context of each school or the challenges faced by each teacher in their daily practice.

These programs also fail to advance toward a more critical approach that fosters educators' reflection. Therefore, it becomes necessary to implement

alternatives that address the demands and gaps in initial teacher education, contributing to a shift from mere reflection to critical reflection. In the words of Lisita et al. (2001, pp. 109–110): “teachers who produce knowledge about both the thinking and the practice of teaching, so that the development of these attitudes and capacities enables them to reconstruct knowledge, articulate theoretical and practical understandings, and produce changes in their professional practice.”

In this sense, this study is guided by the following question: What motivations and challenges permeate collaborative planning and the development of activities involving Physics and the Arts? Accordingly, the objective of this study is to identify and analyze the motivations and challenges that permeate collaborative planning and the development of activities involving Physics and the Arts in the context of continuing professional development.

Methodological Approaches

To meet the objectives proposed in this study, we developed a continuing professional development course for Physics Teachers (PT) and Arts Teachers (AT). The course was grounded in interdisciplinarity and collective construction, and it was conducted in a non-hierarchical learning environment. Throughout the course, we integrated theoretical and practical elements to strengthen collaborative planning among teachers from these areas.

Our investigative approach is outlined in structured stages that allow us to identify elements for continuously planning and adjusting the course design. Throughout our discussions, Design-Based Research (DBR) (Kneubil & Pietrocola, 2017; Brown, 1992; Collins, 1992) emerged as the most suitable methodology, as it aligns with the problems and objectives of this investigation. This will be discussed in further detail later on.

The expected results are aligned with the principles of DBR, as discussed by Kneubil and Pietrocola (2017), who emphasize that this type of research aims at outcomes related to the learning process of the didactic knowledge associated with the instructional “target” content. These results are relevant for examining school conditions, as well as the potentials and challenges involved in the development of interdisciplinary practices among Arts and Physics teachers.

Thus, this methodology aims to promote a practice that introduces innovative elements into the educational environment while simultaneously conducting studies on the process of this innovation in the classroom (Brown, 1992). To this end, the

methodology includes a set of investigative stages, according to Kneubil and Pietrocola (2017), namely: (i) selecting the topic and defining the design principles; (ii) developing the design itself; (iii) implementation; (iv) evaluation; and (v) redesign.

i) Stage of topic selection and formulation of design principles: In this stage, we selected the theoretical frameworks that align with the perspective we aim to adopt in order to meet the proposed objectives. In this case, we used a Freirean perspective to guide the teacher education course we designed; that is, we sought to organize a non-hierarchical formative space grounded in a horizontal perspective, in which all subjects and forms of knowledge are valued. These ideas run counter to a banking model of education, in which teaching is understood "as an act of depositing, in which the students are the depositories and the educator is the depositor" (Freire, 1987, p. 37), and they oppose vertical structures which, as Freire (2013) states, are rigid structures in which there is no room for dialogue. From this perspective, in a dialogical process, each participant assumes the role of teacher-student and/or student-teacher. Thus, we aim to work with theoretical and practical components related to the planning process, with a view to strengthening collaborative work and the development of teaching activities that integrate Arts and Physics.

Connected to these issues, Lisita et al. (2001) identify several perspectives on teacher education, among which the Social Reconstruction Perspective stands out. This perspective advocates for the preparation of teachers who promote a critical education grounded in ethical and democratic principles and oriented toward social justice. In this context, teachers are encouraged to reflect critically on teaching and on the social context in which it unfolds. Our continuing professional development proposal is also grounded in this perspective, which means it is linked to the pursuit of transforming the socially established environments that shape educational spaces.

ii) Stage of developing the design itself: In partnership with a teacher educator from the field of Arts, we organized a plan for five sessions with Arts and Physics teachers in training, facilitated by two Physics teachers and one Arts teacher. This plan is available in Tonini (2022).

iii) Implementation stage: Across the five course meetings, 14 Teachers in Continuing Professional Development (PD-T) participated actively in discussions about expectations and challenges related to interdisciplinary activities involving Arts and Physics. Initially, 23 PD-T answered the Diagnostic Questionnaire (DQ) and attended the first meeting, but throughout the course only 14 maintained consistent participation in most activities. These participants were organized into three interdisciplinary groups: Group 1 included 1 Arts Teacher (PD-AT) and 4 Physics

Teachers (PD-PT); Group 2 included 2 PD-AT and 3 PD-PT; and Group 3 included 2 PD-AT and 4 PD-PT, although one of the Arts Teachers had to withdraw halfway through, leaving only 1 PD-AT in that group.The themes selected by the groups were: nineteenth-century paintings and optics (Group 1), pointillism and the electromagnetic spectrum (Group 2), and a historical overview of astronomical representations in the Arts (Group 3). Despite the heavy workload of some participants and the challenges of the online format, the groups made progress in developing their proposals. Throughout the meetings, additional materials were provided to support the construction of the teaching sequences, and time was dedicated to addressing questions and suggestions from the groups. In the final meeting, Groups 1 and 3 presented their proposals, while Group 2 did not attend. At the end of the course, participants were asked to finalize their sequences and respond to a Final Questionnaire (FQ).

iv) Evaluation Stage: We conducted a qualitative study based on the PD-T responses in questionnaires and on the statements recorded during the meetings, using Bardin's (2016) Content Analysis method. The process followed three stages: pre-analysis, material exploration, and results treatment. In the pre-analysis stage, we transcribed the statements from the meetings and conducted a cursory reading of the transcriptions and questionnaire responses. In the material exploration stage, we carefully read all the content and highlighted, using the same colors, the excerpts that addressed similar topics, with each color representing a different code. In the final stage, results treatment, we grouped the excerpts that addressed the same topics, and based on the goals of the study, two main categories emerged: (i) motivations for interdisciplinary work and (ii) challenges of interdisciplinary work. These categories were presented throughout the analysis of each working group's statements, in order to show how motivations and challenges appeared in the process of planning the joint activities.

v) Re-design stage: Based on the evaluation stage, the proposal was revised in order to address the gaps we identified throughout the investigation.

Creative Connections: The Effects of Integrating Physics and Arts on Lesson Planning

Given the objective of this study—namely, to identify and analyze the motivations and challenges that permeate collaborative planning and the development of activities involving Physics and Arts in the context of continuing

professional development—we began by analyzing the PD-T statements in the DQ and FQ.

As previously mentioned, the teachers were divided into three groups and tasked with developing a joint teaching sequence. Of the 14 active participants, 5 were in Group 1, 5 in Group 2, and 4 in Group 3, distributed between Physics teachers (PD-PT) and Arts teachers (PD-AT). Only Group 1 managed to fully complete its teaching sequence and present it during the final meeting, while Group 3 presented part of its proposal without completing the written record. Group 2, in turn, did not present the collective plan. This overview indicates that, although all groups made progress in their discussions, only 33% fully completed the proposal, revealing practical difficulties in systematizing interdisciplinarity. The teaching sequence developed by the groups aimed to address the interests and challenges faced by the teachers. Accordingly, the work shared by the groups in the course's Virtual Teaching and Learning Environment (VTLE) served as support material for the entire cohort, enabling everyone to access it, contribute to the process, and suggest improvements.

To facilitate identification of the context of each excerpt, we will use DQ and FQ when the statements come from the questionnaires, and for comments made during the meetings, we will use the letter "M" followed by the meeting number (M1, M2, M3, etc.). Additionally, to preserve the participants' identities, we adopt the abbreviations "PT" for Physics Teachers and "AT" for Arts Teachers, followed by a number, in accordance with the ethics committee guidelines (approval number 5,098,857).

Initially, to examine the motivations for interdisciplinary work, we will review each working group. The development of each meeting and the complete teaching plans are available in Tonini (2022).

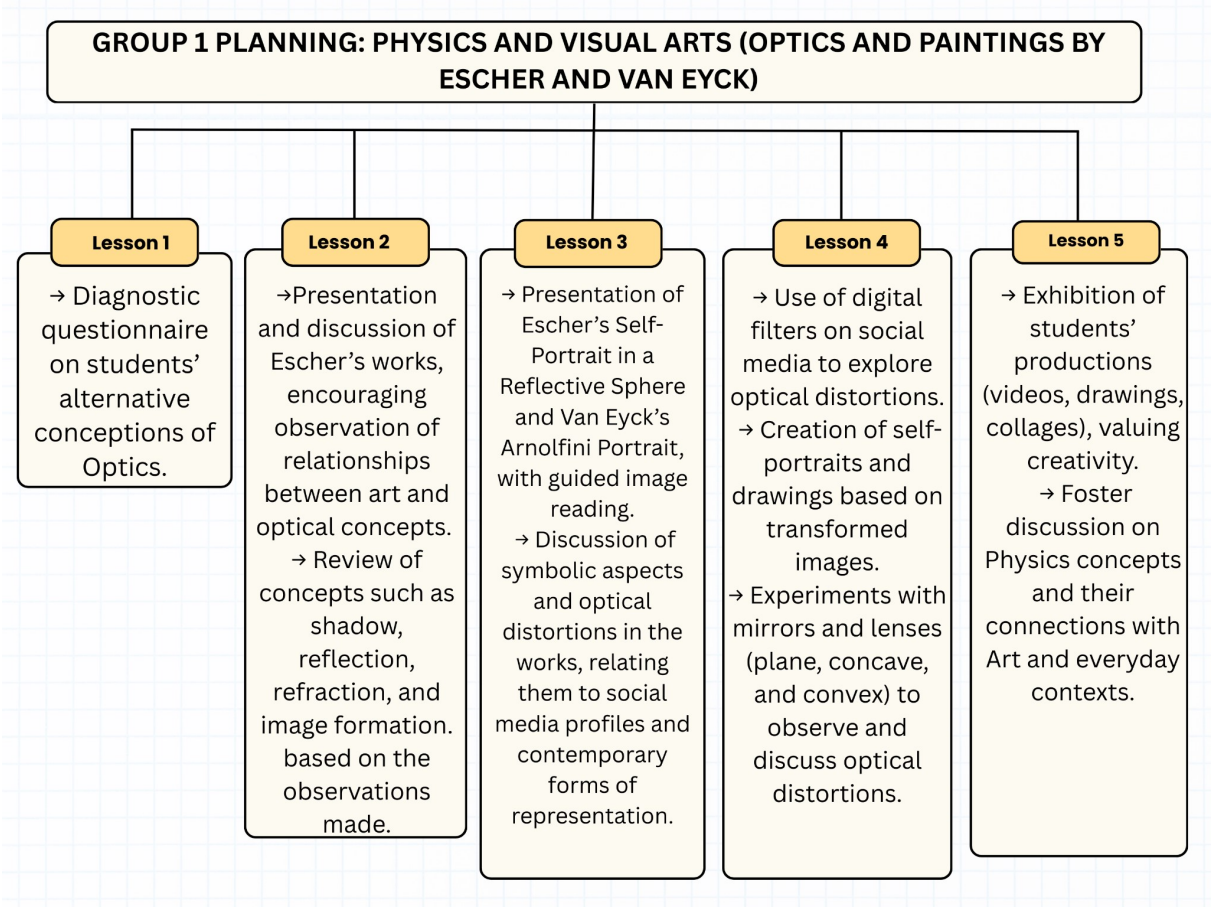
Group 1- Optics and the Artworks of the Renaissance and the 19th Century

Group 1 chose to work with the theme of concave and convex mirrors in artworks. They selected two artworks to support the construction of their teaching sequence, which served as guiding references for their planning: The Arnolfini Portrait (1434) by Jan van Eyck and Hand with Reflecting Sphere (1935) by MauritsCornelis Escher. The proposed sequence included a total of five lessons and presented an introduction, a rationale, and the objectives of the plan. Complementary videos were suggested to help other teachers understand the artworks mentioned. A

summarized version of the teaching sequence developed by the group is presented in the diagram in Figure 1.

Figure 1

Schematic Outline of the Planning Developed by Group 1



Source: Adapted from Tonini (2022)

Note. [Image description] The image shows the schematic outline of the teaching sequence developed by Group 1, organized into five interconnected lessons. At the top, there is a box titled Group 1 Planning: Physics and Visual Arts (Optics and Paintings by Escher and Van Eyck). Below it, five horizontally aligned boxes display brief descriptions of the group's collective planning. Box 1 – Lesson 1: Diagnostic questionnaire on students' alternative conceptions of Optics. Box 2 – Lesson 2: Presentation and discussion of Escher's works, encouraging observation of relationships between art and optical concepts. Review of concepts such as shadow, reflection, refraction, and image formation based on the observations made. Box 3 – Lesson 3: Presentation of Escher's Self-Portrait in a Reflective Sphere and Van Eyck's Arnolfini Portrait, with guided image reading. Discussion of symbolic aspects and optical distortions in the works, relating them to social media profiles and contemporary forms of representation. Box 4 – Lesson 4: Use of digital filters on social media to explore optical distortions. Creation of self-portraits and drawings based on transformed images. Experiments with mirrors and lenses (plane, concave, and convex) to observe and discuss optical distortions. Box 5 – Lesson 5: Exhibition of students' productions (videos, drawings, collages), valuing creativity. Foster discussion on Physics concepts and their connections with Art and everyday contexts. [End of description].

The sequence begins with a questionnaire to assess students' alternative conceptions, followed by the presentation of the proposal developed by two teachers, one Physics Teacher and one Arts Teacher. The lesson focused on image formation

based on Escher's artwork, in which students would engage in an image-reading activity and take part in a dynamic using TikTok filters to create image distortions. Considering the distortions caused by these filters, a self-portrait activity was proposed, allowing students to combine elements from the two artworks and then share the images they produced with the class.

Overall, no difficulties regarding collaborative work were reported within the group, as we can observe in the excerpts from its members:

> […] It was very smooth, especially because I was the only one from Arts in my group. **I think the greater challenge was for the Physics teachers, who depend on one another in order to write while working with different schedules** [emphasis added] (AT-04-FQ)
> […] I did not find the proposal difficult, **the greater challenge was organizing the collective work** [emphasis added] (PT-01-FQ)
> […] It was not difficult. The group interacted well. **The greatest challenge is the time available for us to exchange ideas**. The rush of everyday life is sometimes a limiting factor [emphasis added] (PT-09-FQ)

The analysis of the excerpts illustrates how different aspects of group work were perceived by Arts and Physics teachers, highlighting the influence of communication, the time available, and the way collaboration was established on the success of teamwork. The excerpt from AT-04 mentions that the group-work experience was "very smooth," mainly because this teacher was the only Arts teacher within the group. This suggests that the nature of the discipline, the organization of the work, and the level of interdependence among group members may directly influence how difficulties are perceived. Teachers who work more autonomously, as is the case in some disciplines, may face fewer challenges related to direct collaboration.

On the other hand, the excerpt also highlights that the greatest challenges were related to the need for collaboration among Physics Teachers, who "depend on one another in order to write, and they have different schedules." This indicates that, in situations where interdependence is higher, organization and communication among teachers become critical factors. However, even with this strong need for collaboration, the reports do not mention major difficulties, which suggests that the groups were able to overcome these obstacles. This aspect resonates with Fourez et al. (2002), as it indicates that fragmentation into "fractions of knowledge for fractions of time" creates practical obstacles to integration, but also shows that interdisciplinarity emerges precisely from the effort of negotiation and collaboration among those involved.

The statement from PT-01 raises an important point: "I didn't find the proposal difficult; the greater challenge was organizing the collective work" Although the proposal itself was not considered complicated, organizing the group activities presented a challenge. This aspect fits within the category of challenges of interdisciplinary work, as it highlights the teachers' engagement and their willingness to overcome organizational barriers in favor of collective construction. It also points to a common issue in any collaborative work: the need to coordinate different people, with different working styles and limited schedules, to achieve a common goal.

The statement from PT-09 highlights another relevant issue: "The greatest challenge is the time available for us to exchange ideas. The rush of everyday life is sometimes a limiting factor." This shows that although the motivation for interdisciplinary work was present, the lack of objective time conditions prevented deeper progress. This difficulty had already been noted by Leite et al. (2018), who identify work overload as one of the main obstacles to continuing professional development. Along these lines, Fourez et al. (2002) also observes that the compartmentalization of knowledge and institutional resistances create structural barriers that limit the development of interdisciplinary practices, reinforcing that the obstacles go beyond the organizational level. This reflects a reality common among education professionals, who often need to balance multiple responsibilities at the same time, as discussed in Tonini (2022).

The absence of reports of significant difficulties, even in the face of this time-related challenge, can be seen as an indication that the groups were able, in some way, to adjust their schedules and find moments for exchange that were sufficient for the smooth progress of the work. This may have been facilitated by flexible meeting arrangements, the use of asynchronous digital communication tools, or effective prior planning that allowed for greater fluidity in collaboration.

At the same time, it was possible to observe a reflective process within this group throughout the meetings. Among the group's concerns, particular attention should be drawn to their perceptions regarding collaborative planning and the relationship between the two areas, as we can see in the following excerpt:

> […] For now, our planning is quite stagnant, because we have not yet discussed whether this activity will take place in the Arts class or in the Physics class. **I would prefer for both teachers to work simultaneously, but our writing is still dichotomous**, it is still split. It seems that anyone reading our planning will notice this separation between having a Physics class and an Arts class. […] We still have not defined whether the classes will be conducted with the teachers working separately or together, which is why everything is still very dichotomized. **But it**

> **would not be as interesting if it were separated, because each one would still remain in their own box** [emphasis added] (PT-01-M4)

The statement from PT-01-M4 reveals both the willingness and the challenges involved in implementing an interdisciplinary project effectively. When analyzed through the lens of Bardin's (2016) Content Analysis, this statement initially falls under the category of challenges of interdisciplinary work, as it makes explicit the division between the areas and the difficulty of overcoming traditional disciplinary structures. However, at the same time, the excerpt expresses a motivation for integration, since the teacher conveys a desire to work simultaneously and collaboratively. This ambiguity confirms the interpretation offered by Fourez et al. (2002), who emphasizes that the compartmentalization of knowledge creates obstacles to interdisciplinarity but also opens space for creative processes of recombining knowledge. In turn, Benedicto (2021) highlights that considering Science and Art as culture means recognizing them within social and political intersections, which reinforces the relevance of the teacher's expressed desire to integrate the areas within a single classroom setting.

Thus, despite the difficulties, we can see that the group's search for dialogue was present, generating concerns and moving toward finding alternatives in response to the challenges that emerged throughout the development of the lesson plan. As strategies for addressing the issue of having Physics and Arts teachers teaching simultaneously, during the collective meeting it was suggested that, in the first lesson, the teachers should be together in order to signal that the work was aligned with both areas. If this joint lesson were not possible due to the teachers' demands and schedules, one of them could record an introductory video to be shown during the lesson.

During their presentation in the final meeting, they addressed some of the misalignments experienced between the areas, as reported by PT-01 in the fifth meeting.

> […] **we were startled by the suggestion of having 25 minutes to talk about the artworks. I kept wondering where we would find so much to discuss about them for 25 minutes, since in my case I believe it would take around 5 minutes.** So it is a bit daunting to think about how we are going to explore the artworks being presented from both the Arts perspective and the Physics perspective, and how we are going to sustain the conversation. It would be very interesting if we could actually put this project into practice, I was very curious to find out what would happen in the classroom. [emphasis added]

From an analytical perspective, this excerpt simultaneously highlights challenges—such as organizational misalignments and the dichotomy between the areas—and motivations, expressed in the teacher's curiosity about putting the proposal into practice. This ambivalence relates directly to the different perspectives of knowledge: while Physics is oriented toward the concrete and the exact, Arts explores the subjective and the symbolic. This distinction reflects the conception of Art as a form of knowledge, in which both the artistic product and the pedagogical processes involved in the teaching of Arts are valued, as discussed by Silva and Araújo (2007). These authors emphasize Art as both process and product within the contemporary context of Art Education, which may have generated a sense of unfamiliarity among the physics teachers, who may have held different conceptions about the teaching of Arts

However, there is a limited view of Physics as an exclusively exact science, devoid of human elements, that needs to be challenged. Just like Arts, Physics is also connected to emotions and subjective experiences. These conceptions were gradually deconstructed throughout the group's dialogue, allowing the Perspective of Social Reconstruction in the continuing professional development course (Lisita et al., 2001) and Freire's (2013) ideas on a horizontally constructed formative process to emerge, in which those involved share knowledge and experiences collaboratively. The Freirean approach emphasizes the importance of dialogue and the valuing of multiple perspectives in the educational process, fostering broader critical reflection and helping to overcome fragmented and hierarchical views of knowledge.

Regarding the contribution of the course in encouraging the future development of interdisciplinary proposals, the PD-T responded:

> […] **it was a step further in my interdisciplinary journey.** And it was a great relief to stop thinking about bureaucratic demands and have time to think about lesson planning, which is what teachers enjoy the most, other than being with students in the classroom. [emphasis added] (AT-04-FQ)
> I believe the course **was a space where interdisciplinary thinking could flourish, since there were teachers from different disciplinary backgrounds bringing ideas aligned with this type of proposal.** [emphasis added] (PT-01-FQ)
> […] **this is already a practice I engage in, but the course opened new possibilities.** I often worked with other subjects, but **now I have a clearer sense of the possibilities that the arts can offer to interweave with physics.** [emphasis added] (PT-09-FQ)

Group 1 was able to complete the proposed teaching sequence, and the excerpts highlighted in their responses reveal elements that indicate motivation for interdisciplinary work. When analyzing these excerpts, we identify several factors that encourage teachers' engagement in interdisciplinary approaches. In this way, the

category “motivation for interdisciplinary work” becomes evident, expressed through the expansion of perspectives and the valuing of collaborative planning. These aspects resonate with Fourez et al. (1994), insofar as they understand interdisciplinarity as a creative process that allows for the recombination of knowledge and the expansion of possibilities for teaching practice.

AT-04-FQ states that the course represented “a step further in my interdisciplinary journey”. This suggests that personal development and the expansion of knowledge function as motivational factors. The same teacher highlights the relief of “stop thinking about bureaucratic demands” in order to focus on creating lessons, something they consider one of the most gratifying aspects of the profession. This statement underscores the importance of an environment that supports planning and creativity without administrative pressures, indicating a motivation for teachers to engage in interdisciplinary approaches.

According to PT-01-FQ, the course served as “a space where interdisciplinary thinking could flourish” thanks to the presence of teachers with different educational backgrounds. This collaborative environment, in which diverse perspectives and forms of knowledge are shared, appears to be a strong incentive for interdisciplinary work. PT-09-FQ notes that, although they already practiced interdisciplinary work, the course opened “new possibilities”, especially by highlighting the potential of Arts to intertwine with Physics. This indicates that exposure to new ideas and approaches can broaden the scope of existing pedagogical practices, inspiring teachers to explore new intersections between disciplines.

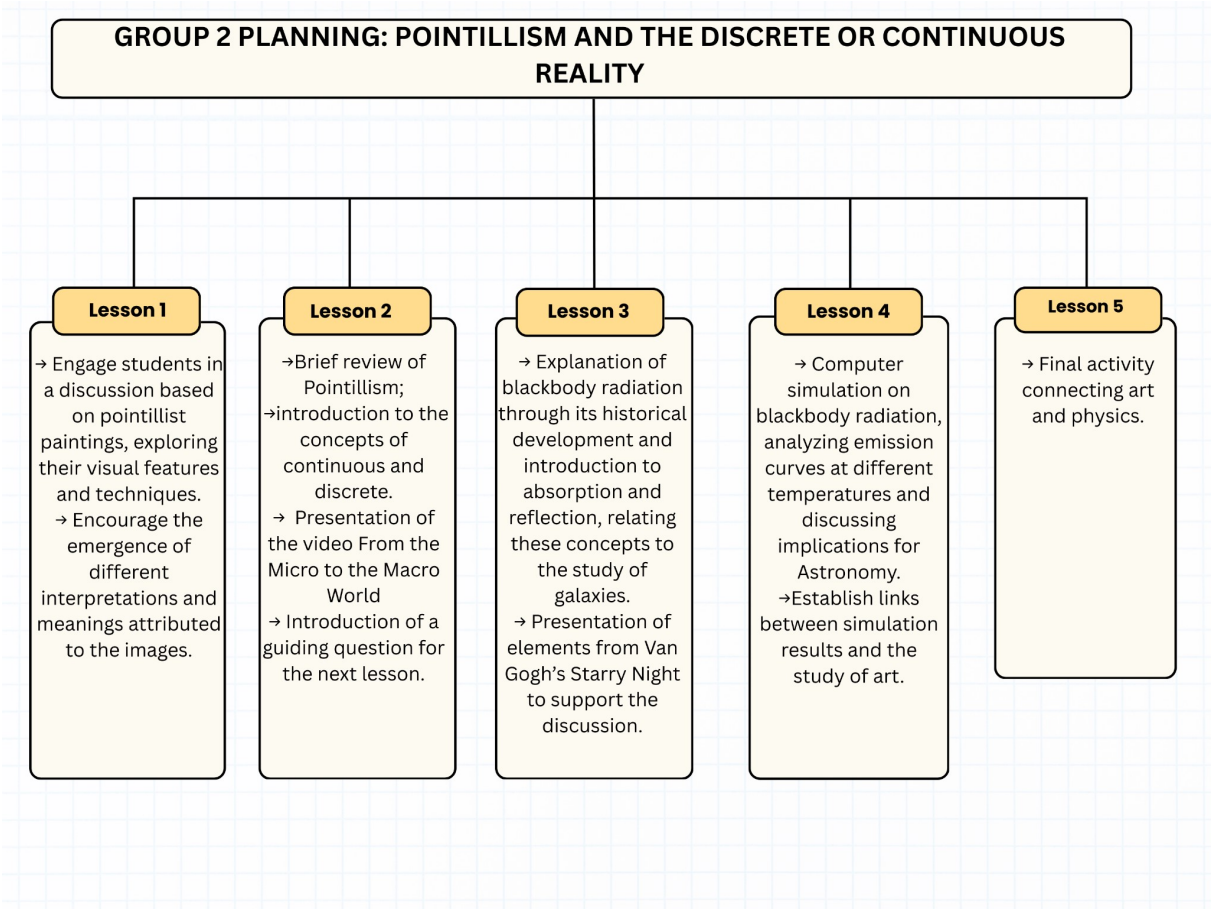
From this perspective, it is essential to highlight the value of dialogue and the construction of a horizontal continuing professional development course (Freire, 2013), in which all forms of knowledge are valued, as well as the pursuit of teaching that goes beyond traditional disciplinary boundaries, allowing for a more comprehensive understanding of phenomena, as advocated by Fourez et al. (1994).

Group 2- Pointillism and the Discrete or Continuous Reality

This group planned to explore pointillist artworks, with particular focus on Georges-Pierre Seurat’s painting “A Sunday Afternoon on the Island of La Grande Jatte” (1884–86). The proposal included analyzing the organization of the dots in the artwork and their variations according to distance. The group then intended to work with concepts of continuous and discrete matter, and finally address content related to blackbody radiation.

Figure 2

Schematic Outline of the Planning Developed by Group 2



Source: Adapted from Tonini (2022)

Note. [Image description] The image shows the schematic outline of the teaching sequence developed by Group 2, organized into five interconnected lessons. At the top, there is a box titled Group 2 Planning: Pointillism and the Discrete or Continuous Reality. Below it, five horizontally aligned boxes display brief descriptions of the group's collective planning. Box 1 – Lesson 1: Engage students in a discussion based on pointillist paintings, exploring their visual features and techniques. Encourage the emergence of different interpretations and meanings attributed to the images. Box 2 – Lesson 2: Brief review of Pointillism; introduction to the concepts of continuous and discrete. Presentation of the video From the Micro to the Macro World.Introduction of a guiding question for the next lesson. Box 3 – Lesson 3: Explanation of blackbody radiation through its historical development and introduction to absorption and reflection, relating these concepts to the study of galaxies. Presentation of elements from Van Gogh's Starry Night to support the discussion. Box 4 – Lesson 4: Computer simulation on blackbody radiation, analyzing emission curves at different temperatures and discussing implications for Astronomy. Establish links between simulation results and the study of art. Box 5 – Lesson 5: Final activity connecting art and physics. [End of description].

Group 2 did not attend the final meeting to present their proposal. Based on our observations, we noticed that this group faced significant difficulties in intertwining the areas and maintaining alignment during discussions. In the fourth meeting, the group had trouble gathering and reaching a consensus on the ideas that had been developed; the AT in this group was unable to follow the proposal

presented by the PTs. Although they had made considerable progress in the third meeting regarding the writing of the plan, the group grew apart when they began to face difficulties in articulating the content more clearly, especially with the AT. We noted a certain dissatisfaction from the group in their responses to the final questionnaire. When asked about the challenges they faced when collaboratively planning the proposal, they responded:

> **I found my experience somewhat frustrating.** My group had very little contact. At first, only one person spoke in the group. **I managed to prepare an Arts lesson, and that person prepared the Physics lesson, that was all.** I soon became demotivated by this, and I was unable to contact the other Arts teacher. [emphasis added] (AT-03-FQ)

This statement indicates a clear lack of motivation. The teacher reports frustration due to the absence of dialogue and collaboration within the group. The feeling that the interdisciplinary work did not progress and the difficulty in establishing contact with other group members contributed to this lack of motivation, as evidenced in the excerpt: “Yes, very much. So much so that we were not able to finish it completely” (PT-05-FQ).

Although not detailed, this response suggests a lack of motivation, mainly due to the inability to complete the work. The incomplete work may reflect the difficulties in interaction and dialogue, which resulted in the group’s lack of motivation: “Certainly, the most difficult part, **beyond the practice itself and working as a team, deal, with the distance and the different areas of knowledge, bringing all these variables into dialogue was a challenge** of its own” (PT-06-FQ).

This statement also reflects the difficulties related to practice, teamwork, distance and variety of knowledge among the group members, as can be seen in this participant’s answer when referring to the difficulty of relating the content in the reading suggestion discussed in the second meeting: “Yes, especially the works that dealt with the movements related to Surrealism and Cubism.” (PT-06-FQ)

Although the planning was being developed in a favorable environment, in which all those involved sought to advance the possibilities of interdisciplinary work, the lack of dialogue made it difficult for this group to complete the planning of their teaching sequence. During the fourth meeting, this group spoke extensively about the difficulties of working in an online format and the challenges of finding a common time for the group to meet and address the parts of the plan that were still unclear. Thus, when the PTs wanted to move from the discussions about pointillist artworks to the blackbody diagram, it became more difficult for the AT to understand and

contribute with their knowledge to the proposal, and from that point on, the misalignments became more evident. This can be seen in the excerpts from the fourth meeting:

> This process […] in the two lessons we planned, in my view, **we did not build an interdisciplinary proposal, because when I thought about planning an Arts lesson, I thought only about Arts, I did not think about Physics. […] Art is appearing as a justification for Physics.** I feel that a bridge is missing. I am only showing the artwork and then showing the explanation of how the author built the piece based on Physics. [emphasis added] (AT-03-M4)

This set of statements falls within the category of "challenges of interdisciplinary work," as it highlights the difficulty of dialogue, of articulating the areas, and of overcoming disciplinary dichotomies. These limitations confirm what Fourez et al. (1994) argues: the simple juxtaposition of content does not guarantee interdisciplinarity, and an effort toward integration is required in order to understand phenomena in their complexity. Thus, it becomes clear that even in favorable environments, interdisciplinary work may face significant planning barriers, which tend to intensify in school contexts. As highlighted in the excerpt from AT-03, the mere presence of different areas in parallel is not enough; it is necessary to build genuine articulation between them.

In this regard, Benedicto (2021) emphasizes that interdisciplinary proposals often place professionals before open and undefined fields, requiring them to acknowledge the limits of their own formative grounding and to seek new knowledge that goes beyond their initial repertoire. This helps explain why the teachers in the group reported frustration and difficulty in making progress: when faced with the unknown, the absence of dialogue and shared time made the challenge even more evident.

In this case, the difficulties faced were tied to the fact that they selected the content beforehand and attempted to contextualize it within the proposal in Arts. In other words, they chose the modern Physics content (blackbody radiation) and, from that point, sought a justification in Arts. This can be seen in the summary of the group's lesson plan, which they sent in the chat during the fourth meeting:

> Lesson 1 – Problematization – creating a connection between Arts and Physics
> Lesson 2 – Brief overview of pointillism and explanation of the concept of radiation, temperature × color.
> Lesson 3 – Explanation of blackbody radiation through its historical development, presenting the concepts of absorption and reflection, and extending them to spectroscopy and the study of galaxies. At this point, it is possible to highlight some elements of the painting in relation to Van Gogh's works (Starry Night painting).
> Lesson 4 – Simulation using PhET.

Lesson 5 – A group activity involving Arts + Physics, which could already be considered an assessment.

Thus, in this group we observed a conception of Art as technique (Silva &Araújo, 2007), in which Arts would be placed in the service of Physics, without engaging in dialogue with the knowledge of Arts itself. Silva and Araújo (2007) argue that this conception of Art is rooted in the early 19th century, when Brazilian positivists viewed Art as important mainly for its contribution to the study of Science, as it was considered a powerful means of developing reasoning and rationalizing emotions, provided it was taught according to the positivist method, which prioritized observation over imagination.

Based on the experience with this group, it is important to highlight the relevance of having someone mediating the dialogue and the process of constructing the sequence. During the meetings, when we dedicated one week to asynchronous activities, one of the mediators remained available to clarify questions, assist with possible difficulties, and encourage a participatory and collaborative process. During this period, some members of Groups 1 and 3 participated, but Group 2 did not attend. The absence of Group 2 may have contributed to the difficulties they faced, since the lack of dialogue with the mediators and with the group members may have limited the clarification of questions and the resolution of problems. This ongoing dialogue during the process is one of the pillars we defend for the continuing professional development course, because without it, it is not possible to establish an interrelation between the areas, as Fourez et al. (2002, p. 29) points out: the effects of disciplinary compartmentalization also fall upon teachers, as they are led to divide the subjects into “independent and well-defined objects”.

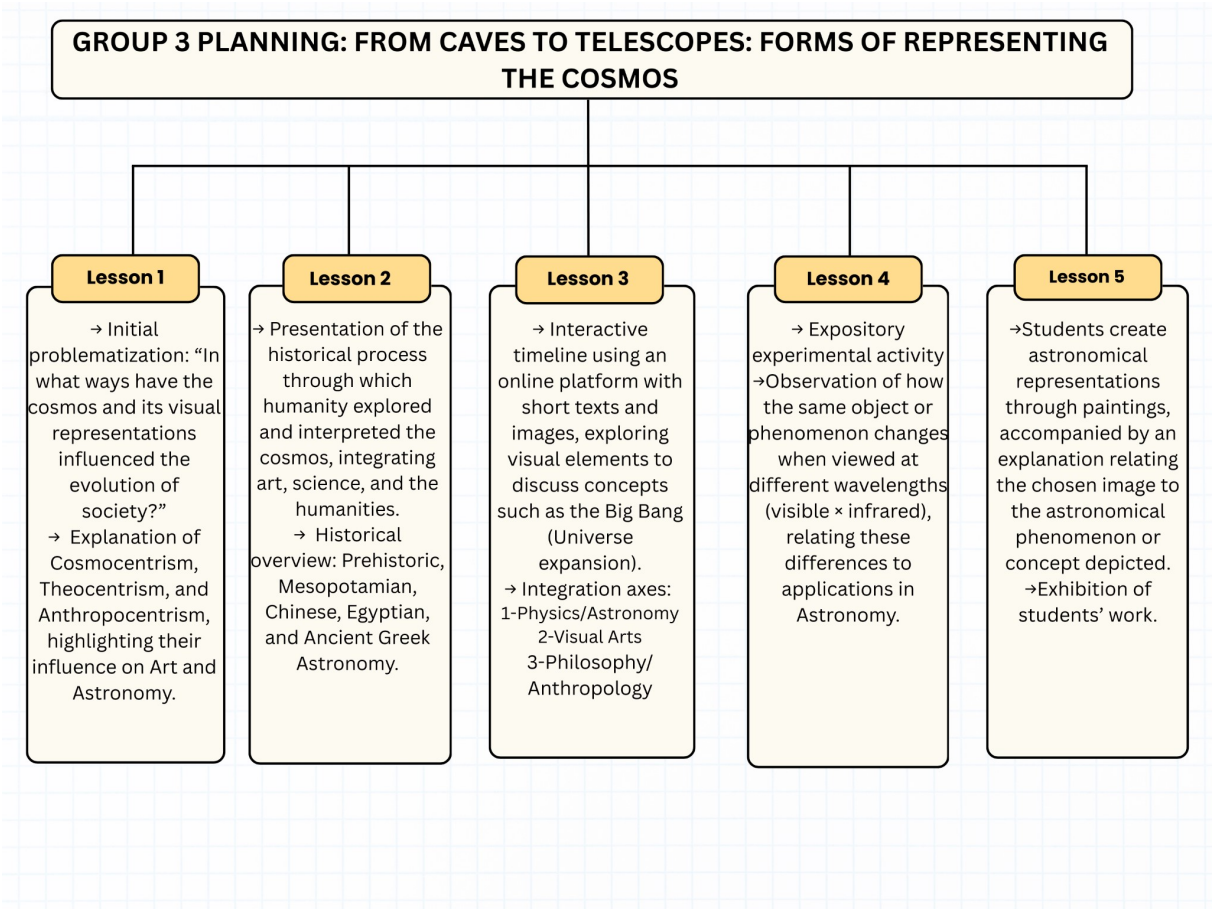
Investigating the reasons for the absence of dialogue, we found that they were related to the workload experienced by many PD-T participants during the continuing professional development course. Thus, we highlight the lack of conditions for these professionals to dedicate themselves to other formative activities, which ultimately compromises their ability to meet interdisciplinary and integrated practice demands, as noted by Leite et al. (2018). Furthermore, as discussed by Figueira-Oliveira et al. (2018), the time required to make such training feasible was also a factor strongly emphasized in the teachers’ statements.

Group 3- From Caves to Telescopes: Forms of Representing the Cosmos

Group 3, which had three in-person members, was able to conduct the content-related discussions more effectively. This group, however, showed greater difficulty in writing the teaching plan, as they did not write down the ideas discussed and, based on what they presented in the final meeting, they were not in agreement with the plan they had submitted. The group's planning, titled "From Caves to Telescopes: Forms of Representing the Cosmos," aimed to address the study of Astronomy and Arts from a historical perspective, exploring the conceptions of different peoples across historical periods, divided into cosmocentrism, theocentrism, and anthropocentrism. From this division, they intended to work with celestial maps and selected paintings depicting shifts in conceptions throughout history.

Figure 3

Schematic Outline of the Planning Developed by Group 3



Source: Adapted from Tonini (2022)

Note. [Image description] The image shows the schematic outline of the teaching sequence developed by Group 3, organized into five interconnected lessons. At the top, there is a box titled Group 3 Planning: From Caves to Telescopes: Forms of Representing the Cosmos. Below it, five horizontally aligned boxes display brief descriptions of the group's collective planning. Box 1 – Lesson 1: Initial problematization: "In what ways have the cosmos and its visual representations influenced the evolution of society?" Explanation of Cosmocentrism, Theocentrism, and Anthropocentrism,

highlighting their influence on Art and Astronomy. Box 2 – Lesson 2: Presentation of the historical process through which humanity explored and interpreted the cosmos, integrating art, science, and the humanities. Historical overview: Prehistoric, Mesopotamian, Chinese, Egyptian, and Ancient Greek Astronomy. Box 3 – Lesson 3: Interactive timeline using an online platform with short texts and images, exploring visual elements to discuss concepts such as the Big Bang (Universe expansion). Integration axes: 1-Physics/Astronomy, 2-Visual Arts, 3-Philosophy/Anthropology. Box 4 – Lesson 4: Expository experimental activity. Observation of how the same object or phenomenon changes when viewed at different wavelengths (visible × infrared), relating these differences to applications in Astronomy. Box 5 – Lesson 5: Students create astronomical representations through paintings, accompanied by an explanation relating the chosen image to the astronomical phenomenon or concept depicted. Exhibition of students' work. [End of description].

However, an experimental activity brought by the group for the presentation day, during the fifth meeting, was not included in the written teaching sequence plan. The objective of the experimental activity was to demonstrate how observations are carried out when using different wavelengths, such as infrared radiation. However, although Group 3 presented an innovative initiative in seeking to integrate the areas, the proposal was not adequately detailed in the written plan. This makes it difficult to understand and share the proposal so that it can be developed in other contexts. In earlier meetings and during the group presentations, it was suggested that the group systematize the ideas formulated in the presentation and include them in the written teaching plan, but no revisions were submitted in the material sent to us. Nevertheless, we were able to identify the causes of these omissions in the teaching plan from the group's responses in the final questionnaire, particularly regarding the difficulties they encountered during the collaborative work.

> Not within my own field of Arts. But, **in the intertwining of the areas, yes**. [emphasis added] (AT-02-FQ)
> It was definitely challenging, but the biggest problem was that I took on the role of teaching assistant after the course had already started, **so I ran out of time**… [emphasis added] (PT-02-FQ)
> This question becomes relative. When we are able to engage in dialogue and already have an overall understanding of the topic as a composition of Physics and Arts, it becomes easy. In my case, however, this month **I received an extraordinary workload, which prevented me from contributing as much as I would have liked**[...]" [emphasis added] (PT-08-FQ).

These excerpts fall under the category of "challenges of interdisciplinary work," as they reveal the difficulty of reconciling external demands and limited time with the need to build effective articulations between distinct areas. As Benedicto (2021) points out, interdisciplinary proposals require teachers to acknowledge the limits of their own formative grounding and to seek knowledge beyond their repertoire, which can generate insecurity and frustration throughout the process. Therefore, we can see that the group was unable to complete the written plan due to the workload they faced during the course activities. The remaining PD-T in the group, such as PT-10

and AT-08, were also unable to continue the sequence of activities for the same reason. Once again, we highlight the challenges linked to the lack of conditions for interdisciplinary work, which compromises dialogue and collaborative engagement. As a motivating factor for interdisciplinary work, we can highlight the following excerpt: “Yes, I am working on a lesson plan to use in the Internship B course in the Physics undergraduate program, and it has been very inspiring to me.” (PT-02-FQ).

We can identify motivation in this PT’s statement, as he mentions that the experience was inspiring and that he is applying the knowledge acquired to develop a lesson plan. The practical application of what was learned in the course demonstrates enthusiasm for interdisciplinary work. It is also important to note that this PT was the one who suggested the experimental proposal to the rest of the group and the one who brought all the experimental equipment for the presentation day, which suggests commitment and motivation toward the activities experienced throughout the formative process. Continuing with the PD-T motivation statements, we have the following excerpt:“I have always had motivation. **The course showed me ways to better organize an interdisciplinary plan**.” [emphasis added] (PT-08-FQ).

The statements by PT-02 and PT-08 also reflect the category of “motivation for interdisciplinary work,” as they express enthusiasm and the desire to apply what was experienced in the course to other contexts. This dimension can be understood in light of Freire (2013), who conceives the formative process as a dialogical and collaborative space in which teachers reorganize their knowledge and find ways to transform their practices.

General Considerations on Collaborative Work

The analysis of the collaborative work makes it possible to identify elements that enhance the formative process, as well as others that become challenges to it. The importance of fostering dialogue around aspects related to interdisciplinary work is evident.

The analyses reveal several elements that characterize motivation for interdisciplinary work. Among these, the teachers’ initial willingness to work collaboratively and the creation of spaces that foster dialogue and exchange of ideas, as they enable connections between the areas and the sharing of knowledge. Added to this is the practical application of what was learned in other contexts, such as internships or classroom settings, as well as the broadening of horizons made

possible by exposure to new possibilities for integrating Physics and Arts. The support material provided also served as an incentive, as it helped contextualize the discussions and inspire reflections, as evidenced in the following excerpts.:

> Yes, especially the works that dealt with the movements related to Surrealism and Cubism. (PT-06-FQ);
> Yes. The more we study, the more we discover the relationship between these areas. In schools, these subjects are treated as completely separate (PT-08-FQ);
> Yes. They were quite useful in this process (PT-09-FQ);
> Very relevant, all the texts were excellent choices (AT-04-FQ);
> I only read the first text presented by the course coordinators. It was interesting (AT-03-FQ).

In addition, the appreciation of collective planning without bureaucratic pressure emerged, as did the development of cordial and affective bonds among the teachers and the perception of interdisciplinarity as a creative space for recombining knowledge, in line with Fourez et al. (1994). Finally, the course was recognized as a dialogical and horizontal environment, consistent with Freire's (2013) perspective, in which different voices were able to express themselves and strengthen participants' engagement.

The written documentation of the dialogues and ideas presented throughout the meetings, as well as of the asynchronous interactions, also proves to be important for the development of the formative process. The accounts from Group 3 highlight the importance of recording the group's notes and discussions, both for organizing the ideas and for structuring the teaching sequence to be developed. In addition, this practice can serve as inspiration for other teachers. In this context, the creation of a collaborative logbook is suggested, in which each group can describe the process of developing the sequence, including the references and resources used. This strategy not only creates a collective memory for the group but also contributes to continuous reflection and to the development of writing skills, which are essential for teacher education (Tonini&Leonel, 2021). When using the Moodle learning platform, for example, the wiki tool can be an effective choice for this purpose.

Another factor identified was the use of digital technologies, which can be associated both with the category "motivation for interdisciplinary work," by enabling permanent records and expanding access to materials, and with the category "challenges of interdisciplinary work," by making immediate cohesion and dialogue among teachers more difficult. Some teachers lived in distant cities, which would have hindered their participation if the course had been conducted fully in person. On the other hand, the remote modality also brought challenges, such as the difficulty of

engaging in asynchronous activities, evidenced by the absence of Group 2 in part of the interactions. This ambivalence echoes what Benedicto (2021) highlights about the interdisciplinary field: open and undefined, it requires professionals to navigate limitations of time and space while simultaneously embracing new possibilities for professional development.

The affinity among group members is also a fundamental factor for ensuring that the PD-T remain aligned and willing to face potential divergences of ideas in interdisciplinary work. We observed that regular interaction and the creation of spaces for collective dialogue strengthen the development of the activities. These elements can be understood within the category of “motivation for interdisciplinary work,” as they reveal the teachers’ willingness to share experiences and build meaningful connections, an aspect aligned with the Freirean conception of the formative process as a dialogical and horizontal practice.

However, simply creating spaces and times for meetings is not enough. The category “challenges for interdisciplinary work” shows that the practice of collaborative planning faces multiple obstacles. The most recurrent one is the lack of time, associated with teacher overload and the difficulty of coordinating schedules. This same issue was identified in the proposal by Figueira-Oliveira et al. (2018), who point to the need to invest in the quality of the time devoted to planning as an alternative. Other challenges concern the difficulties of dialogue and collaboration, such as the absence of contact among members of some groups and the limited collective progress, the dichotomy between areas, and the tendency to reduce Arts to a mere illustrative resource. The remote modality and the low engagement in asynchronous activities also emerged as hindrances, compounded by external demands and by differences in conceptions about the teaching of Arts. Finally, there were problems related to the systematization of the proposals and to the institutional conditions for planning. These limitations confirm Fourez et al.’s (1994) critique that the simple juxtaposition of content does not ensure interdisciplinarity, and they resonate with Benedicto’s (2021) view of this field as open and undefined, requiring teachers to acknowledge the limits of their own formative grounding and seek knowledge beyond their initial repertoire.

In summary, the data show that motivation and challenges coexist within the formative process. While the teachers express enthusiasm and a desire to integrate different forms of knowledge, they also face structural and organizational barriers that must be overcome for interdisciplinarity to be realized as a transformative educational practice.

Final Reflections: Challenges and Possibilities in the Convergence Between Physics and Arts in Education

Based on the above, we found that collaborative work and the sharing of knowledge within the formative space of the course allowed for integration among PD-T from different contexts, bringing together valuable elements for assessing how this collective effort can contribute meaningfully to the school environment. This process proved promising in addressing the everyday challenges faced by teachers who seek to implement interdisciplinary practices, fostering dialogue between disciplines such as Physics and Visual Arts.

However, numerous structural difficulties were also observed, hindering the teachers' full participation in the formative course. The case of Group 2 illustrates this clearly: the high demand of external activities prevented its members from meeting as intended. In addition, some participants struggled to continue the course, experiencing similar limitations. These issues highlight the need to better understand the obstacles that prevent teachers from being released to participate in these formative spaces, thereby avoiding the tendency to place sole responsibility on the teacher for low engagement or limited participation in such initiatives.

On the other hand, despite the challenges faced, the proposals that emerged from the groups' work reveal considerable potential. Even though they were developed in a short period of time and by teachers who did not share the same work context, while also dealing with limitations inherent to online interaction, the proposals demonstrated the ability to meaningfully integrate elements from both disciplines. Such proposals can become powerful pedagogical activities that strengthen the relationship between Physics and Arts in the school context, offering new possibilities for interdisciplinary teaching practices.

In this sense, we hope that this work encourages the development of new pedagogical practices and serves as an incentive for future investigations into the relationship between different areas of knowledge within the school environment. When effectively explored, interdisciplinarity offers new perspectives for teaching practice, promoting an education that is more closely connected to students' contexts and to the demands of contemporary society.

Finally, we highlight the urgency of promoting continuing professional development courses that incorporate the demands and challenges teachers face in their daily work. If these development courses are well planned and managed, it is

possible to overcome the time limitations, as long as these limitations are handled efficiently. Moreover, it is essential to ensure that teachers have the minimum conditions necessary to participate in these formative spaces. Valuing these moments of professional development, with a structure that enables teachers' effective participation, is fundamental for the development of sustainable interdisciplinary practices, contributing to a more integrated and collaborative education.

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