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THE TEACHING OF ELECTROMAGNETIC WAVES FOR STUDENTS WITH AGE-SCHOOL YEAR DISTORTION: AN EXPERIENCE REPORT ABOUT AN INTERDISCIPLINARY PROPOSAL INVOLVING PHYSICS AND GEOGRAPHY

O ENSINO DE ONDAS ELETROMAGNÉTICAS PARA ESTUDANTES COM DISTORÇÃO IDADE-ANO ESCOLAR: UM RELATO DE EXPERIÊNCIA SOBRE UMA PROPOSTA INTERDISCIPLINAR ENVOLVENDO FÍSICA E GEOGRAFIA

LA ENSEÑANZA DE ONDAS ELECTROMAGNÉTICAS PARA ESTUDIANTES CON DISTORSIÓN EN EDAD ESCOLAR: UN RELATO DE EXPERIENCIA SOBRE UNA PROPUESTA INTERDISCIPLINARIA QUE INVOLUCRA FÍSICA Y GEOGRAFÍA

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ABSTRACT: The theme of this manuscript is the teaching of electromagnetic waves in Basic Education. This is an experience report on the development of a didactic proposal that uses Inquiry in an interdisciplinary approach in the disciplines of Physics and Geography; its implementation was analyzed with students who present age-year distortion. To this end, we sought to bring together the scholarly content with the students' day-to-day situations, such as how GPS works and wave propagation, as well as the use of maps and Compass Roses. The target audience was high school students with age-grade distortion from the MUNDIAR Project. Evidence was found not only of mastery of specific content, but also of the development of scientific skills. More specifically, the results indicated that the didactic proposal contributed to students' contextualized learning, including complex abstract concepts, such as the three-dimensional nature of electromagnetic waves.

KEYWORDS: Interdisciplinarity. Age-year gap. Scientific Literacy. Wind rose.

RESUMO*: O presente manuscrito aborda o ensino de ondas eletromagnéticas na Educação Básica. É um relato de experiência sobre o desenvolvimento de uma proposta didática que usa o Ensino por Investigação em uma abordagem interdisciplinar nas disciplinas Física e Geografia; foi analisada sua aplicação com estudantes que apresentam distorção idade-ano. Buscou-se aproximar os conteúdos ensinados de situações do dia-a-dia do aluno, como o funcionamento do GPS e a propagação das ondas, bem como a utilização de mapas e Rosa dos Ventos. O público alvo foram estudantes de ensino médio com distorção idade-ano escolar do Projeto MUNDIAR (PA). Foram encontrados indícios não apenas do domínio dos conteúdos específicos, mas também do desenvolvimento de habilidades científicas. Os resultados indicaram que a proposta didática contribuiu para o aprendizado dos alunos, inclusive de conceitos abstratos complexos, como o caráter tridimensional da propagação da onda eletromagnética.*

PALAVRAS-CHAVE*: Interdisciplinaridade. Defasagem idade-série. Alfabetização Científica. Rosa dos Ventos.*

RESUMEN*: El tema de este manuscrito es la enseñanza de ondas electromagnéticas en la Educación Básica. És un relato de experiencia sobre el desarrollo de una propuesta didáctica que utiliza la Enseñanza Basada en la Indagación con un enfoque interdisciplinario en las disciplinas de Física y Geografía; se analizó su implementación con estudiantes que presentan distorsión edad-año. Buscamos acercar los contenidos impartidos a situaciones cotidianas del alumnado, como por ejemplo el funcionamiento del GPS. El público objetivo eran estudiantes de secundaria con distorsión de edad y grado del Proyecto MUNDIAR (PA). Se encontraron evidencias no sólo del dominio de contenidos específicos, sino también del desarrollo de habilidades científicas. Los resultados indicaron que la propuesta didáctica contribuyó al aprendizaje contextualizado de los estudiantes, incluyendo conceptos abstractos complejos, como la naturaleza tridimensional de la propagación de ondas.*

PALABRAS CLAVE*: Interdisciplinariedad. Distorsión edad-año. Alfabetización Científica. Rosa de los vientos.*

Introduction

The age–grade distortion, or educational delay, refers to the condition of students who are older than the recommended age for their current grade level. According to the 2021 Brazilian School Census (Inep, 2021), although children generally enter the education system at the appropriate age, the percentage of students affected by this distortion increases over the years, reaching 27% among boys and 22% among girls by the end of high school. In other words, on average, one in every four Brazilian students completes high school older than the recommended age, with this rate being higher in the public education system.

The report "*Overview of Age–Grade Distortion in Brazil*" (Unicef, 2018) highlights several initiatives to address this issue, including the development of student-centered curricula that enable the implementation of pedagogical approaches in which "teachers and students are co-authors of the activities and, together, learn and teach from one another in an articulated and integrated manner" (Unicef, 2018, p. 13, our translation). The interdisciplinary approach, by fostering integration and interaction among scientific disciplines (Oliveira; Araujo; Veit, 2024), can serve as an alternative for promoting differentiated methodological activities that contribute to reducing the aforementioned rates.

Within this context, several Brazilian states have developed targeted projects for students facing age–grade distortion. The State of Pará, for instance, implements the MUNDIAR Project, part of the *Pact for Education of Pará* (Pará, 2015), whose main goal is to accelerate the learning process of students experiencing age–grade distortion who are regularly enrolled in Basic Education (BE). The project seeks to improve educational quality within the state public school system by promoting differentiated methodological activities in schools, where a single teacher acts as a learning facilitator for specific groups of students affected by age–grade distortion.

This article adopts an interdisciplinary approach to explore concepts from Physics and Geography, aiming to reflect on the teaching and learning of electromagnetic waves within the context of GPS-based location and mapping, focusing on high school students with age–grade distortion.

As the study was developed within the scope of a professional master's program by one of the authors (Castro, 2020), this work is characterized as an experience report on the pedagogical activity designed and implemented by the researcher in his role as a facilitating teacher in a high school class participating in the MUNDIAR Project in the State of Pará.

Theoretical Framework

This section discusses the historical development of interdisciplinarity, inquiry-based teaching, and their interrelation within an interdisciplinary framework.

Interdisciplinarity and Science Teaching in Basic Education

Interdisciplinarity in schools aims to provide students with experiences that reflect their real-life contexts, such as "clarifying a situation, solving a problem, or understanding something in its context as close as possible to the real or everyday" (Ostermann; Mozena, 2016, p. 297, our translation). In Brazil, the first scholars to study interdisciplinarity were Fazenda (1996) and Japiassu (1976).

In everyday life, situations that require scientifically grounded solutions are rarely as simple or idealized as those presented in Basic Education classrooms. Generally, it is necessary to draw upon more than one discipline to adequately solve a real problem. Therefore, it is crucial that students be exposed to teaching approaches that increasingly approximate real-world situations from the early stages of Basic Education.

The *Base Nacional Comum Curricular* (National Common Curricular Base) reinforces the importance of such approaches in school practices, assigning teachers the responsibility to

> decide on the forms of interdisciplinary organization of curricular components and strengthen the pedagogical competence of school teams to adopt more dynamic, interactive, and collaborative strategies regarding the management of teaching and learning (Brasil, 2017, p. 18, our translation).

However, studies indicate that, despite its inclusion in official documents, interdisciplinary practice remains distant from the reality of Brazilian schools (Castro, 2020). This gap is related to the historical fragmentation of knowledge into different fields over the centuries. When this disciplinary fragmentation manifests in teacher education programs, as seen in undergraduate curricula, it tends to be reproduced in Basic Education teaching practices (Dameão *et al.*, 2021; Gasperi; Emmel, 2023).

Starting in the 12th century, knowledge began undergoing a process of specialization, resulting in an increasing fragmentation of disciplines. As Sommerman (2005) points out, over the centuries, a gradual separation emerged among religion, philosophy, and science. Thinkers grounded in rationalist and empiricist epistemologies—such as Newton, Galileo, and Copernicus—"established the foundations of modern science" (Sommerman, 2005, p. 1, our translation).

In the 17th century, for example, physics—strongly influenced by René Descartes' rationalism—shifted away from its contemplative dimension, which once connected physics to metaphysics, and began emphasizing discursive reason. Scientism and mechanism came to dominate, reinforcing the growing fragmentation of knowledge.

> Although the rationalist–empiricist paradigm contributed significantly to technological advancement, as discussed above, it also intensified disciplinary fragmentation. Humanity came to believe that understanding the whole was possible by decomposing it into parts. There was an overvaluation of human senses—particularly vision—which were greatly enhanced by instruments that extended their capacity, such as telescopes, microscopes, particle accelerators, and others (Sommerman, 2005, p. 2, our translation).

In opposition to this reductionist movement, from the mid-20th century onward, academic research began to emerge with the purpose of promoting cooperation among disciplines at various levels, seeking to mitigate the problems caused by the hyper-specialization of knowledge. In other words, these studies sought to follow the opposite path of what had been—and still is—occurring within academia.

These interactions among disciplines, depending on the level at which they occur, receive different designations, such as multi-, pluri-, inter-, and transdisciplinary, among others. Although the conceptual meanings of these terms have evolved over the decades, what remains consistent is "the idea that they represent movements which arose in response to the fragmentation of knowledge" (Bicalho, 2011, p. 116, our translation).

In *multidisciplinarity*, there is minimal integration among disciplines; cooperation does not occur, but rather juxtaposition. Piaget proposed that multidisciplinarity represents the lowest level of integration (Santomé, 1998).

At the other extreme lies *transdisciplinarity*, which involves a higher degree of interaction among various fields of knowledge. In this approach, the interplay among disciplines is so profound that it becomes difficult to delineate their boundaries. According to Silva, Santana, and Nascimento (2021), transdisciplinarity represents an advanced stage of integration, with no rigid boundaries between disciplines, encompassing multiple dimensions of reality and seeking to articulate them in a unified manner for the construction of scientific knowledge.

However, moving toward a transdisciplinary approach in teaching, when applied to the educational context, is complex. Therefore, this study adopts an *interdisciplinary interaction*, which, according to Japiassu and Marcondes (2001), enables two or more disciplines to interact with each other, either through the exchange of ideas or through the mutual integration of concepts.

In this work, the *interdisciplinary approach* (Fazenda, 1996) is combined with the *Inquiry-Based Teaching* (IBT) strategy (Carvalho, 2004, 2014; Zompero; Laburú, 2016).

The choice of an interdisciplinary approach—especially when considering specific classes of students experiencing age–grade distortion—has been rarely discussed in the literature. In the context of Science Education for Youth and Adult Education, Silva and Reis (2025, p. 33, our translation), based on bibliographical research and field studies with teachers, concluded that

> although many educators claim to apply interdisciplinarity in their pedagogical practices, its effective implementation still faces significant obstacles, such as the scarcity of didactic resources and the difficulty of engaging students.

Thus, it is evident that proposing studies based on this approach, particularly within teacher education programs, is crucial—such as the one presented herein.

Inquiry-Based Teaching

Just as interdisciplinarity seeks to address real-world problems, *Inquiry-Based Teaching* (IBT), particularly through the resolution of problem situations, also aims to engage students with issues closely related to their lived reality (Ferreira, 2019).

Oliveira *et al*. (2017) define open-ended problems as those without pre-established solutions—problems that “present an initial state that is only partially known, refer to real-world events with outcomes consistent with reality, and require students to make judgments and construct arguments to defend their solutions” (Oliveira *et al*., 2017, p. 1, our translation). To solve such problems, students must develop skills that go beyond memorizing content, such as creating idealizations, using “estimations, approximations, formulating hypotheses, testing solutions, monitoring, and regulating methodological procedures” (Oliveira *et al*., 2017, p. 2, our translation).

According to Zompero and Laburú (2011, p. 68), this pedagogical approach is based on investigation and enables "the enhancement of students' reasoning and cognitive skills, as well as cooperation among them, while fostering an understanding of the nature of scientific work." This teaching strategy, predominant in North American education, is rooted in the philosophical thought of John Dewey. For Dewey, students should undergo educational experiences. Such experience does not necessarily depend on a favorable learning environment, stimulating equipment, group work, or students' attitudes. "Instead, the educational experience is evoked—it arises from the students' participation in the environment as they create and engage in the unfolding drama of their own storyline" (Wong *et al.*, 2001, p. 322, our translation).

Zompero *et al*. (2017) highlight that investigative activities can be developed through various approaches. However, the literature shows consensus regarding certain key characteristics of such activities. Among these is that they must always originate from a problem to be analyzed, from which students can "plan activities, interpret information, and communicate results" (Zompero *et al*., 2017, p. 425, our translation).

Hence, *Inquiry-Based Teaching* aims to enhance students' development of skills related to scientific argumentation, rather than to train them as professional scientists. As emphasized by Scarpa, Sasseron, and Silva (2017), there is a distinction between teaching designed to cultivate citizens interested in scientific topics and teaching intended to form scientists. These authors advocate for the use of IBT focused on developing competencies associated with solving everyday problems based on scientific principles. They argue that "this type of teaching will contribute both to the understanding of science and its processes and to the formation of critical citizens capable of taking informed positions on everyday issues that require engagement with scientific matters" (Scarpa; Sasseron; Silva, 2017, p. 12, our translation).

In this sense, *Inquiry-Based Teaching* seeks to promote *Scientific Literacy* (SL) among students. This literacy aims to guide Science Education planning so that it fosters "the construction of practical benefits for individuals, society, and the environment" (Sasseron; Carvalho, 2008, p. 334, our translation).

Methodological Approach

The study presented herein was developed within the scope of a professional master's program and consists of an experience report on the development, implementation, and analysis of a didactic proposal, as well as a discussion of the main results observed.

The implementation context of the didactic proposal was a first-year high school class of the MUNDIAR Project at a public school in the state of Pará, located in a municipality within the metropolitan region of Belém. The master's student—one of the authors of this work—was acting as a *facilitator teacher* in this class. The group initially comprised 35 enrolled students, of whom only 26 effectively attended the course. The participants were between 18 and 21 years old.

Grounded in the principles of interdisciplinarity and Inquiry-Based Learning (IBL), the activity sought to construct a problematizing situation for the teaching of electromagnetic waves through an interdisciplinary perspective. The chosen scenario was the search for a missing person in the neighborhood where the school was located. To solve the challenge proposed by the facilitator teacher, students applied scientific concepts from Physics and Geography in an integrated manner—specifically, the propagation of electromagnetic waves and their relationship with GPS-based location in maps.

Data collection was primarily conducted through two sets of open-ended questionnaires, each containing five questions. Each set was administered at the end of each instructional stage and contributed to the assessment of students' learning. The first stage consisted of the application of the interdisciplinary didactic sequence (described in the following section), which involved maps, scale, spatial location, direction of wave propagation, and GPS operation. The second stage focused on the propagation of electromagnetic waves and their practical applications.

In addition to the written responses, some activity sessions were recorded and filmed by the classroom teacher, and these materials were later transcribed for analysis.

The data analysis was based on Scientific Literacy (AC) indicators proposed by Sasseron and Carvalho (2008), which encompass logical and proportional reasoning, as well as data handling through information sequencing and hypothesis testing, validation, and justification (Sasseron; Carvalho, 2008).

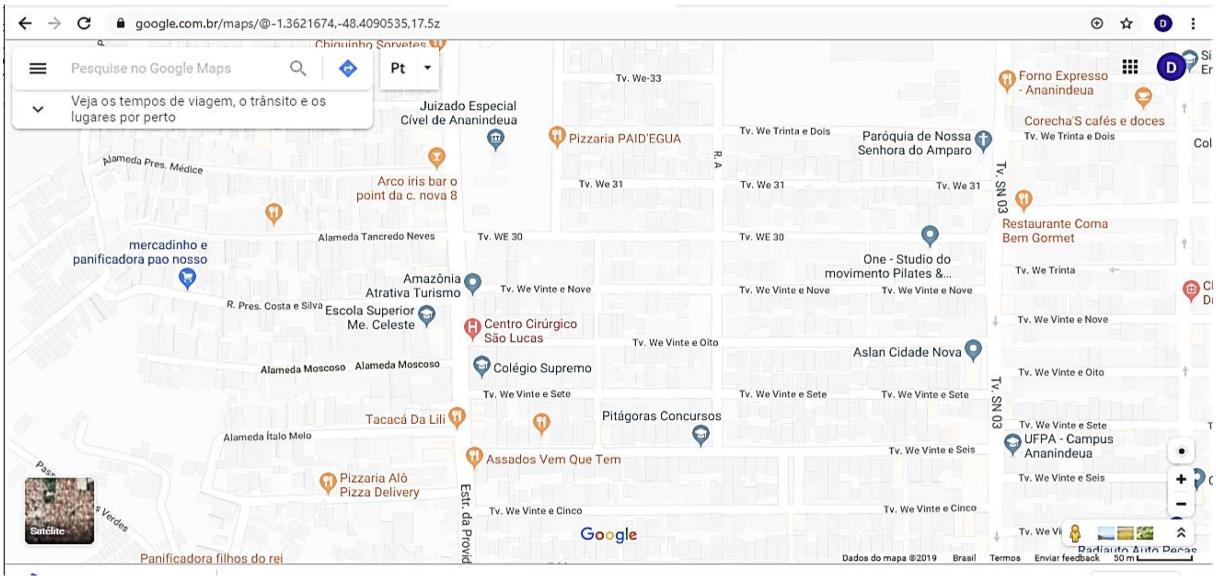
Presentation of the Didactic Proposal

The didactic proposal was divided into two stages, each composed of six sessions. Each stage was termed a "*Mission*", as students were expected to complete a specific challenge (or mission) throughout the process. The estimated time for each mission was three 45-minute class periods.

The first mission consisted of locating the source of a signal emitted by a cell phone using a neighborhood map and other provided materials. During this activity, students explored some characteristics of electromagnetic waves, relating them to geographic concepts. Specifically, the learning objectives were to explain the three-dimensional nature of electromagnetic wave propagation and understand the function and use of the compass rose for spatial orientation and map localization.

Figure 1 presents the map used by the student teams to locate the signal emitter. To identify the point on the map from which the signal was being transmitted, students were required to draw three circles with different radii. The intersection point of the three circles represented the probable location of the emitter.

Figure 1 – Map used by the teams to locate the missing student



Source: Castro (2020).

The decision to use a smaller-scale map, rather than a citywide or state map, aimed to contextualize the activity with familiar reference points that students could potentially recognize in their own locality. Moreover, employing a broader regional or state map would have hindered the visibility of points, a limitation that could be mitigated by using larger paper sizes—though at a higher printing cost. Therefore, the A4 paper format was chosen as the most cost-effective and accessible option.

The second mission continued the study of electromagnetic waves and challenged students to find a way to block the propagation of such a wave—in this case, a cell phone signal. Throughout its implementation, concepts such as refraction and reflection of electromagnetic waves were explored, as well as their nature and applications in various everyday technologies familiar to the students.

The missions were designed to integrate the subjects of Physics and Geography in an interdisciplinary manner. Furthermore, the didactic strategy of Inquiry-Based Learning (IBL) was employed so that each team member assumed the role of an investigator in solving the proposed challenge. Thus, in addition to addressing the specific content knowledge mentioned above, both missions included moments dedicated to reflecting on the procedures adopted in solving the challenges, as well as constructing causal relationships, during which students were encouraged to argue and justify their actions, hypotheses, and conclusions. These activities aimed to promote the development of AC, in alignment with several indicators proposed by Sasseron and Carvalho (2008).

Tables 1 and 2 present a summary of the two missions and their respective moments.

Table 1 – Mission I and its Six Stages

STAGE 1: LOCATING THE SIGNAL EMITTER
1ST MOMENT: CONTEXTUALIZING THE THEME At first, the teacher introduces the theme of the didactic proposal, initiating a discussion with students about the human need for orientation and spatial location—an ancient practice that dates back to the Age of Discovery, when navigation relied on constellations, astrolabes, and compasses. During this stage, images of astrolabes and compasses are presented for students to observe and manipulate.
2ND MOMENT: PRESENTING THE PROBLEM (MISSION 1) At this stage, the challenge to be addressed during Mission 1 is presented: *A student from the school is lost and has an electronic device that emits signals. A rescue team is searching for this student and has detected the distress signal through three towers. Your mission is to locate, on the map, the point from which the signal is being transmitted using only a compass, a ruler, and the following information:* *The signal was detected by a tower located at the Juizado Especial Cível de Ananindeua, at a distance of 250 meters;* *The signal was detected by a tower located at UFPA – Ananindeua Campus, at a distance of 305 meters;* *The signal was detected by a tower located at Paróquia de Nossa Senhora do Amparo, at a distance of 270 meters.*

3RD MOMENT: INTERACTING WITH THE AVAILABLE MATERIALS The class is divided into teams and provided with rulers, compasses, and a map of the neighborhood (Figure 1) to manipulate. During this stage, students discuss and test possible hypotheses in order to identify, on the map, the precise point where the lost student is located, based on the signals captured by the receiving towers.
4TH MOMENT: HOW DID YOU SOLVE THE PROBLEM? After completing the challenge, each team is encouraged to describe the procedures they followed in solving the problem.
5TH MOMENT: PROVIDING CAUSAL EXPLANATIONS Once the students explain how they solved the challenge, they are encouraged to reflect on *why* they chose certain procedures. This reflection is guided by questions such as: *Why was it necessary to use the compass instead of the ruler?* *Would the location be more accurate if there were more towers?*
6TH MOMENT: DEEPENING THE LEARNING PROCESS At this point, a short text is presented explaining how GPS technology works, its relation to the propagation of electromagnetic waves, and the triangulation technique used for locating signals.

Source: Castro (2020).

Table 2 – Mission II and its Six Stages

STAGE 2: ELECTROMAGNETIC WAVES
1ST MOMENT: CONTEXTUALIZING THE THEME The teacher provides a brief explanation of the topic, highlighting that electromagnetic waves are an integral part of students' daily lives.
2ND MOMENT: PRESENTING THE PROBLEM (MISSION 2) At this stage, the challenge to be addressed during Mission 2 is introduced: *Using A4 paper sheets, aluminum foil, and two cell phones, find a way to prevent the signal from the transmitting phone from reaching the receiving phone.*
3RD MOMENT: INTERACTING WITH THE AVAILABLE MATERIALS After distributing the materials, students are given time to develop and test their hypotheses collaboratively, with the teacher acting as a facilitator and mediator of the discussion.
4TH MOMENT: HOW DID YOU SOLVE THE PROBLEM? Students are encouraged to describe the steps they took and the reasoning behind their solutions.
5TH MOMENT: PROVIDING CAUSAL EXPLANATIONS After the groups present their solutions, students are guided to reflect on the reasoning behind their actions through questions such as: *Why was it not possible to block the cell phone signal using only paper sheets?* *Could other materials or configurations be used to achieve different results?*
6TH MOMENT: DEEPENING THE LEARNING PROCESS In this stage, the class collectively reads a short text about electromagnetic waves, consolidating the knowledge developed during the activity.

Source: Castro (2020).

The teacher began the first mission with a problematization exercise, providing a brief introduction to the topic by discussing the Age of Discovery and how people once oriented themselves to travel long distances, using, for example, compasses. He then pointed out that modern cell phones contain applications that simulate compasses and allow precise geolocation through GPS. At this point, images of astrolabes were distributed to the class, initiating the first group discussion on the topic.

In the second stage, the problem was presented to the students. They were divided into groups, and the challenge of locating the lost student on the map was introduced through a collaborative discussion. Figure 2 presents the proposed mission.

Figure 2 – Challenge Proposed in Mission 1

MISSÃO 1

*Um aluno da escola está perdido e dispõe de um aparelho eletrônico que emite sinais. Uma equipe de busca está à sua procura e captou o seu sinal de socorro através de três torres. Sua missão é encontrar no **mapa** o local de onde está sendo emitido o sinal de socorro usando apenas o compasso, a régua e as seguintes informações:*

*1.O sinal foi captado em uma torre localizada no **Juizado Especial Civil de Ananindeua** a uma distância de 250 m;*

*2.O sinal foi captado por uma torre localizada na **UFPA – Campus Ananindeua** a uma distância de 305 m;*

*3.O sinal foi captado por uma torre localizada na **Paróquia de Nossa Senhora do Amparo** a uma distância de 270 m.*

Source: Castro (2020).

In the third stage of Mission 1, rulers and compasses were provided to the groups. The students tested these materials and concluded that the towers could be represented as circumferences with radii corresponding to the distances indicated in the problem statement, and therefore, the use of a ruler would not be appropriate. In this way, students were encouraged to recognize the three-dimensional nature of waves, even while working with a two-dimensional map.

After all groups reached the conclusion that the possible location of the signal emitter corresponded to the intersection of the three circles, in the fourth stage, the students were encouraged to describe how they managed to solve the proposed problem. The purpose of this stage was to develop students' ability to report and communicate the outcomes of their actions.

The mission concluded with a moment dedicated to constructing causal relationships, during which students were asked why they chose to use the compass instead of the ruler, whether the number of towers affected the accuracy of the emitter's location, and whether the signal propagated in multiple directions or only one, as well as whether it occurred in two dimensions—like ocean waves—or in three dimensions, as in radar waves.

The objective of this moment was to provide students with the opportunity to engage in argumentation based on their own actions and observations, since, according to Oliveira and Carvalho, as cited in Zompero and Laburú (2016, p. 29, our translation), "students, as they discuss and argue about a given phenomenon, are cognitively processing their understanding of the activity."

The structure of the second mission followed the same sequence of stages, as presented in Table 2.

Results and Discussion

The analysis was based on the written texts produced by students at the end of each of the two stages of the Didactic Proposal, as well as on the transcription of videos and audio recordings made during its implementation. Although students were identified by name in the written responses, in this study, they were anonymized using the letter "A" followed by a numerical sequence (A1, A2, A3, and so forth), assigned randomly to prevent identification. This nomenclature was consistently maintained throughout both stages.

Below is the analysis of the main excerpts from the transcription. The complete study can be found in Castro (2020).

Mission 1

In the first stage of Mission 1, not all students were confident about the best way to locate the emitter—specifically, whether they should use a ruler or a compass—although most had already realized that the possible location of the emitter would correspond to the intersection of the three circles. This becomes evident from student A3's statement: "*Where is it coming from? ... Which direction? ... How are we going to know?*" In other words, the three-dimensional nature of the electromagnetic wave—in this case, the emitted signal—had not yet been fully understood.

As the activity progressed, the same student began to reconstruct his reasoning through reflection, although still working under the hypothesis that the signal traveled in only one direction. When asked by the teacher whether the number of towers affected the accuracy of the location, student A3 started to associate the emitter's location with something three-dimensional, which he referred to as a "*turn*" (meaning a circle).

Student A4 believed that an additional tower would make localization easier: "*I think it would improve!*" Similarly, the same student noted that having fewer towers would make localization more difficult: "*I think with fewer towers it would be harder to find.*" Student A4 associated the number of towers with the precision of the localization, stating: "*Ah! One more reference point!*" Student A3 added: "*Then we would try to connect, to interlink the point that would be closest to them.*"

In this case, it is possible to associate the Scientific Literacy (SL) indicator "*hypothesis formulation*" with the responses of students A3 and A4, as they sought to relate the variable *number of towers* to the emitter's location. Although the causal relationship being expressed was not yet fully determined, it is also possible to identify the SL indicator "*proportional reasoning*" (Sasseron; Carvalho, 2008), which the students used to establish a relationship between the presented variables. It is important to note that the triangulation technique used to locate signals was only introduced in the final stage of systematization and deepening.

When the teacher asked where the same principle they had applied on the map might be used, several students answered "*GPS*" or "*Google Maps.*" Student A1 responded: "*It uses references from several satellites! … It's as if there were several towers here. The point shows where you are.*" This demonstrates the SL indicator "*seriation,*" as the students relied on their prior knowledge and experience to support the understanding of the presented concept (Sasseron; Carvalho, 2008).

Drawing an analogy with GPS functioning, the towers receiving the signal acted as satellites, while the signal emitter represented the mobile device, i.e., the GPS within the phone. Regarding the precision of the emitter's location, the group associated it with the number of satellites—in this case, the number of towers.

The fact that the vast majority of students owned cell phones with internet access and regularly used location-based applications such as Google Maps and ride-hailing apps enriched the activity, as this technology—GPS—is part of their everyday context. This aligns with one of the objectives of interdisciplinarity, which, according to Ostermann and Mozena (2016, p. 297, our translation), is "to clarify a situation, solve a problem, or understand something in its context as close to the real or everyday as possible."

When asked about the map's orientation in relation to the cardinal points, student A5 answered that it would be "by the compass," actually referring to the compass rose symbol present on maps, which serves precisely to indicate cardinal directions. Student A3 demonstrated some prior knowledge about map orientation—aware that there was a standard, though unable to explain it: "*This way I know is north! I don't know, this way is north!*" Here, the SL indicator "*seriation*" also appears, allowing the student to use his prior knowledge to support the localization task.

Mission 2

When asked which material they would use to solve the challenge of blocking the signal emitted by a cellphone, student A7 drew from personal experience and responded that they would use aluminum: "*because aluminum, by itself, heats up. It's a… it's a… a paper that heats up, that serves to heat things, that's why we use it in… in hair!… when we bleach hair!*".

Student A7 proposed an initial hypothesis. For this student, aluminum should be used to take the cellphone out of range—that is, to prevent the emitted signal from reaching the receiving cellphone—because it heats up. The student associated this reasoning with an everyday observation: aluminum heats up when used during hair bleaching. It is worth noting that this student worked in a beauty salon, once again illustrating how the proposed challenge was closely related to the lived realities of students with an age–grade gap. Furthermore, hypothesis generation corresponds to one of the Scientific Literacy indicators described by Sasseron and Carvalho (2008).

One of the students mentioned that some people use this method to bypass sensors, thereby blocking signals to commit theft: "*because when thieves go to steal something, they use aluminum foil to wrap the goods so it doesn't generate area.*" Another student, in an unrecorded comment, stated that they had seen something similar in a TV series they watched. Here, it is possible to identify the Scientific Literacy indicator "sequencing," since the student used prior experiences to establish a foundation for addressing the proposed question.

Student A2, following the first hypothesis, added: "*that might be true, because this is really a metal; if you put energy into it, it will transmit energy. If you take a stripped wire and* *place it here—oh! If you touch this top part, it'll conduct electricity!*" This statement reveals another Scientific Literacy indicator—"justification" (Sasseron; Carvalho, 2008).

Student A6, in turn, proposed a different hypothesis: that the material should be aluminum because it reflects the signal: "*I think it reflects the signal, and it can't reach the device.*" Student A2 then related the experiment to everyday life: "*this is also used in food, right, professor?*" At this point, the teacher took the opportunity to contextualize the reflection of electromagnetic waves using practical examples from the students' daily lives, particularly cooking, since one of the students worked as a cook.

Based on the hypotheses raised, the teacher and students tested A6's hypothesis that aluminum foil "reflects the signal and prevents it from reaching the device." To do so, the teacher used a laser-emitting device to draw an analogy between light and a cellphone signal—both being electromagnetic waves. At this stage, the Scientific Literacy indicator "testing hypotheses" (Sasseron; Carvalho, 2008) was applied.

In summary, the data analysis revealed a lower occurrence of indicators related to logical and proportional reasoning compared to those associated with sequencing, as well as hypothesis generation and testing. It is important to note that this pattern was observed both in the first mission, which required a higher level of abstraction related to the three-dimensional nature of electromagnetic waves, and in the second mission, which demanded a lower degree of abstraction. It can thus be concluded that, although these students are at the high school level, they still experience difficulties in relating abstract concepts and have not yet fully developed logical and deductive reasoning skills.

Final Considerations

The aim of this study was to develop a didactic proposal—specifically, an Inquiry-Based Teaching Sequence—from an interdisciplinary perspective, integrating the subjects of Geography and Physics to explore the topic of electromagnetic waves, focusing on students with an age–grade gap.

One of the objectives of the Teaching Sequence was to encourage students, through the resolution of two problem situations presented as "missions," to think about practical applications related to the propagation of electromagnetic waves and their use in locating people through maps, as well as to understand certain conceptual aspects, such as their three-dimensional nature and interaction with matter. In this sense, the activities were designed to promote students' SL.

The dialogue between the different disciplines was therefore enhanced during the problem-solving process, often requiring a complete integration of knowledge from both Geography and Physics—for instance, the use of maps combined with an understanding of the propagation characteristics of electromagnetic waves—making the disciplinary boundaries indistinguishable in order to address the proposed challenge.

The results of this research demonstrate that the use of new methodological approaches, particularly active learning methodologies—that is, those that move students from a passive role as spectators to active participants in the construction of their own knowledge—is of great value for improving the teaching and learning process, not only in Physics but also in other disciplines, such as Geography. Specifically, in the context of students with an age–grade gap, the data revealed several SL indicators, such as sequencing and hypothesis generation, which appeared most frequently.

Because the problems proposed were situated within the students' real-life contexts—such as the GPS used in navigation and transportation applications, and the electromagnetic waves underlying cellphone signals—they enriched the learning experience by stimulating students' curiosity and encouraging active engagement.

It is worth emphasizing the importance of students' conceptual construction based on their initial hypotheses. In the case of electromagnetic waves, this became particularly evident when one of the hypotheses was tested through the reflection of a laser beam on aluminum foil. From this observation, students were able to associate the reflection of cellphone signals with everyday situations, such as cooking food wrapped in aluminum foil.

Another significant moment was the construction of the concept of the three-dimensionality of electromagnetic waves. Although presented in textbooks, the analysis of the results clearly revealed the complexity of this concept and the challenge of overcoming preexisting spontaneous conceptions within the students' cognitive structures, such as the notion of unidirectional propagation. This was evident at the end of the first mission, when some students still believed that the transmitter could be located using only a ruler.

Finally, it is important to note that, although the proposal was implemented with students experiencing an age–grade gap, it can be effectively applied in other educational contexts, thereby strengthening the adoption of interdisciplinary teaching approaches.

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- **Conflicts of interest**: The study adhered to ethical standards during the research. The educational intervention was applied to the master's student's own class, authored by Castro.
- **Ethical approval**: Submission to an Ethics Committee was not required, as the State Department of Education does not mandate ethical approval for the implementation of didactic proposals within the master's student's own classroom.
- **Data and material availability**: The data and materials used are included in Castro's (2020) master's dissertation and can be found in the analysis chapter.
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