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Operative invariants of the conceptual field of water applied by students in youth and adult education

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ABSTRACT

This paper reports on the results of activities developed while building an Interdisciplinary Island of Rationality. Fifteen students from the Youth and Adult Education (EJA) program took part in the research, in the context of the Conectando Saberes (Connecting Knowledge) project at a state school in Mato Grosso do Sul (MS). The activities developed, as proposed by Gerard Fourez, aimed to evaluate the potential operative invariants of the water conceptual field, as expressed by the students while developing an Interdisciplinary Island of Rationality, based on the following concrete issue: "How can the decrease in rainfall in Mato Grosso do Sul affect the supply of water that reaches our homes"? The results show that the students began to build paths to identify theoretical knowledge through real everyday situations, establishing relationships between scientific concepts and natural phenomena. By further exploring the conceptual field of water, the students could better understand how water-related issues impact both locally and globally, thus allowing them to broaden their view of the challenges faced in their own community, as well as allowing EJA students to integrate their diverse experiences into the discussion, making learning more relevant and meaningful for them. Thus, a more engaging, meaningful, and sustainable education took place, encompassing the differences and particularities of each student, contributing to the formation of informed and aware citizens.

KEYWORDS: Youth and Adult Education; Water; Interdisciplinarity.

Invariantes operatórios do campo conceitual da água mobilizados por estudantes da educação de jovens e adultos

RESUMO

Este artigo apresenta os resultados de atividades desenvolvidas durante a construção de uma Ilha Interdisciplinar de Racionalidade. Participaram da pesquisa 15 estudantes da modalidade Educação de Jovens e Adultos (EJA), no contexto do projeto Conectando Saberes, de uma escola pública da rede estadual de ensino de Mato Grosso do Sul (MS). As atividades desenvolvidas, conforme propõe Gerard Fourez, tiveram como objetivo avaliar os possíveis invariantes operatórios do campo conceitual da água, explicitados pelos estudantes durante o desenvolvimento de uma Ilha Interdisciplinar de Racionalidade, com base no seguinte problema concreto: "Como a diminuição dos períodos de chuva no MS podem afetar o abastecimento da água que chega às nossas casas"? Os resultados demonstram que os estudantes começaram a construir caminhos na busca por identificar os conhecimentos teóricos por meio de situações reais do cotidiano, estabelecendo relações entre os conceitos científicos com fenômenos naturais. Ao explorarem o campo conceitual da água, os estudantes puderam compreender melhor como as questões relacionadas à água causam impactos, tanto em nível local quanto global, auxiliando-os a ampliar a visão sobre os desafios enfrentados em sua própria comunidade, bem como proporcionando assim aos estudantes da EJA integrar suas experiências diversas à discussão, tornando o aprendizado mais relevante e significativo para eles. Dessa maneira, promoveu-se uma educação mais engajadora, relevante e sustentável, abrangendo as diferenças e particularidades de cada estudante, contribuindo para a formação de cidadãos informados e conscientes.

PALAVRAS-CHAVE: Educação de Jovens e Adultos; Água; Interdisciplinaridade.

INTRODUCTION

Youth and Adult Education (EJA, for its acronym in Portuguese) is a modality of education introduced by the federal government to ensure that young people, adults, and older adults have the human right to lifelong learning. The EJA, according to Bortoli and Nogueira (2023), enables the conclusion of primary and secondary education for all those who, regardless of circumstances, did not have access or were unable to pursue their studies at the appropriate age. The Law of Guidelines and Bases of National Education (LDB) No. 9.394/1996, stresses that education systems must guarantee appropriate educational opportunities free of charge, considering the characteristics of the students, their interests, as well as living and working conditions (Brasil, 1996).

In the state of Mato Grosso do Sul, SED/MS Resolution No. 1,410, of February 17, 2000, published in the Official Gazette No. 5206, of February 18, 2000, authorizes the operation of Supplementary Primary Education Courses in the Youth and Adult Education Modality, setting standards for its operation in schools in the state education network. Currently, in Mato Grosso do Sul, this modality is offered by the state education network through course projects, one of which is the Pedagogical Course Project Conectando Saberes, in place since 2020.

This project allows us to develop different methodologies and interdisciplinary projects to be implemented in the EJA. Therefore, we carried out this research following the guidelines set out in the documents that guide the EJA. Based on the pedagogical project of the school where our research was implemented, we found that the EJA modality should be based on an environment that fosters the exchange of knowledge and dialogue, encouraging the collaborative construction of knowledge. According to Figueredo and José (2022), this approach aims to overcome the paradigm of traditional teaching and align scientific teaching with the social context, enabling students to be active participants throughout the learning process.

Therefore, the guidelines of the pedagogical project for Youth and Adult Education in Mato Grosso do Sul are aimed at overcoming the challenges that hinder the schooling process inherent to this public. Thus, teachers and researchers can implement teaching activities to help prepare these students (Mato Grosso do Sul, 2020).

The link between social and cultural contexts allows us to contribute to the learning and schooling process, preventing this group from being sidelined from achieving a quality education that guarantees young people, adults, and older adults not only access but permanence, from start to finish, in this schooling process, covering all groups equally in the educational process built by the EJA in the state of Mato Grosso do Sul (Mato Grosso do Sul, 2020).

Given the guidelines of the official documents regulating the EJA, it would be a useful approach to develop a teaching methodology aimed at integrating areas of knowledge. The goal would be to develop a learning process focused on solving problem situations linked to the reality of the students and the environment of which they are a part. Thus, interdisciplinary methodology could provide a way of developing skills such as criticality, dialog, and the ability to deal with real situations based on the proposed object of knowledge.

In this context, we believe that studying the concept of water, combined with an interdisciplinary methodology, provides EJA students with a substantial opportunity to advance their learning in the field of science teaching. The relevance of studying water in the social, cultural, and scientific contexts allows students to understand and broaden their concepts about everyday life, as well as the relationships between human beings and scientific phenomena, overcoming superficial interpretations of the surrounding reality (Becker, Rossato & Elllwange, 2019).

Research and the implementation of teaching methodologies have evolved to shift away from the traditional learning paradigm, in which the student is seen as a passive participant in their own educational process, limited to merely assimilating knowledge. Instead, the aim is to create approaches that allow the student to play an active role, collaborating with the teacher for more meaningful learning (Rodrigues et al., 2011).

For Moreira (2018), the traditional method is no longer effective in the learning process, as it does not provide an understanding of the concepts in terms of their applicability in everyday life, especially if these concepts are used to examine everyday situations, which is consistent with our object of study.

By working with scientific knowledge and connecting it to students' everyday lives, we enable the development of science teaching from an interdisciplinary perspective, in other words, integrating knowledge from different disciplinary components. This approach allows us to tackle everyday issues with a more consistent and meaningful understanding for the student (Maingain et al., 2008).

According to Rodrigues (2010), disciplinary knowledge is often introduced to the participant in the learning process in a fragmented way, isolating each discipline. This leads to difficulties in working with everyday issues, as one discipline alone cannot supply all the concepts needed to teach real situations.

Such situations have prompted teachers and researchers to design and build teaching methods that bring the students' context to the center of the learning process. Embracing the student's reality tends to make learning less uninteresting and more dynamic, making it more engaging for those taking part in the action (Valente et al., 2017).

The National Common Core Curriculum (BNCC) is the official document responsible for the curriculum guidelines for the different modalities of basic education. It sets out a range of skills and competencies that enable teaching with an interdisciplinary bias, linking the areas of knowledge. Thus, the student will be able to move towards autonomy, criticality, and dialog about the desired object of study, i.e. "education must affirm values and stimulate actions that contribute to the transformation of society, making it more humane, socially just, and also focused on the preservation of nature" (Brasil, 2018, p. 8).

From this perspective, studying the conceptual field of water allows for the development of interdisciplinary actions that draw on situations from the student's daily life to approach scientific knowledge, as well as building more structured and consistent learning about this object of study (Mundim & Santos, 2012).

It is worth noting that the general competencies of basic education, outlined in official documents, also apply to the EJA, guiding the didactic process in the building of knowledge, the development of skills, and the shaping of attitudes and values:

> [...] a normative document that defines the organic and progressive set of essential learning that all students must develop throughout the stages and modalities of Basic Education, to ensure their learning and development rights [...] (Brasil, 2018, p. 7, emphasis added).

The pedagogical proposal of the EJA is grounded in the duties of the State to guarantee access to education for people in all age groups who have not had the opportunity to complete their studies, emphasizing the importance of this public's previous knowledge and experiences, aiming to offer them the same quality education as regular education and meet their educational needs (Mato Grosso do Sul, 2020).

Maingain et al. (2008) describe interdisciplinarity as associated with the development of the learning process, through actions that transform educational practice, thus transposing traditional teaching and enabling participants to develop appropriate means, such as skills, criticality, and capacity for dialogue, in addition to the scientific knowledge needed to deal with real and contextualized situations. It is worth highlighting that the practice of interdisciplinarity in EJA teaching should arise naturally, requiring awareness on the part of educators regarding the educational context (Silva, 2023).

In line with our proposal, Dal-Farra and Valduga (2015) argue that implementing and systematizing interdisciplinary practices requires organizational and didactic efforts on the part of one or more teachers. Therefore, we developed an interdisciplinary action with EJA students based on concepts covering the conceptual field of water. Consistent with the authors, we understand that water, being an essential natural resource for life and the survival of species, is a relevant conceptual field for the application of interdisciplinary practices.

Finally, studying the conceptual field of water allows us to take different approaches to teaching science, thereby opening a range of options for interdisciplinary actions to be developed in the learning process. Thus, by studying this conceptual field, we sought to evaluate the potential operative invariants of the conceptual field of water, as explained by the students while developing an Interdisciplinary Island of Rationality, based on the following concrete problem: “How can the decrease in rainfall periods in Mato Grosso do Sul affect the water supply that reaches our homes?”.

THE IMPACT OF THE POLARIZATION OF EJA STUDENTS AND THE METHODOLOGIES DEVELOPED BY TEACHERS IN THE SCHOOL ENVIRONMENT

We conducted our research at a public school in the municipality of Campo Grande – MS, in a peripherical neighborhood of the south region of the capital. Recent changes have been undertaken by the State Secretariat of Education aiming to restructure the high school curriculum, turning most of the schools in the region into full-time education. Thus, the EJA modality has been increasingly sought by young adults who cannot keep up with full-time education and need to concentrate on a single school period.

In the restructuring implemented in Mato Grosso do Sul by the State Department of Education in high school, some subjects, especially those in Natural Sciences, now comprise only one 50-minute class per week, under an agreed curriculum that limits the possibility of changes by teachers. Meanwhile, the evaluation structure of the EJA, which is modular, provides for performance evaluations every six months, unlike regular high school, in which evaluations are every two months. In addition, in the EJA, teachers of natural sciences subjects have two 50-minute classes a week for each subject, which provides teachers with greater flexibility, since the curriculum allows them to develop more meaningful teaching strategies, adapted to the context and particularities of the EJA. (Mato Grosso do Sul, 2020, p. 5).

Several managing challenges arise for teachers and researchers when faced with the structure of EJA, especially in terms of the coexistence between youngsters, adults, and older adults, which can lead to further conflicts, such as poor cooperation and dialogue between them. Such challenges demand extra skills from teachers to ensure a productive, respectful, and meaningful learning environment.

However, it is worth pointing out that, despite the challenges, age polarization can also contribute significantly to the learning process in the EJA. The presence of younger students, who are often more motivated to understand the object of study, can inspire and encourage adults and older people. Furthermore, young people can be more flexible with their commitments, which could allow them to focus more on their studies and help support other colleagues in the classroom. This dynamic approach could foster a more interactive and enriching classroom environment, reflecting positively on the methodologies developed by teachers, as well as on the learning process as a whole.

INTERDISCIPLINARY ISLAND OF RATIONALITY

The methodology known as Interdisciplinary Island of Rationality (IIR) was developed by Gérard Fourez and introduces options for creating a path based on an interdisciplinary perspective, in which the student designs representations when faced with real situations, combing theoretical knowledge with everyday phenomena. The author proposes that this methodology is a means to start building scientific and technological literacy by fostering autonomy and criticality, in addition to dialogue and theoretical knowledge-related skills for students to work with in everyday situations (Fourez, 1997).

According to the author, once the concrete problem is defined, students must harness their knowledge throughout the stages of the IIR, which are: cliché; spontaneous overview; consultation with experts; practical experience; in-depth opening of black boxes with the help of experts; partial synthesis of the island; opening of black boxes without the help of experts; and final synthesis.

The IIR methodology, as proposed by Gerard Fourez, provides the ideal dynamic for an interdisciplinary action to be designed, focusing on approaching different publics and contexts, which fits into the EJA group, as shown in our study. The representation designed by the end of the work stages allows the participants to express their ideas throughout the process of solving the concrete problem presented (Fourez, 1997).

THE THEORY OF CONCEPTUAL FIELDS AND OPERATIVE INVARIANTS

Gérard Vergnaud's Conceptual Fields Theory (CCT) provides the theoretical framework used to analyze the development of students' knowledge development. Based on Vergnaud (1990), learning progress is built upon the individual's experiences acquired both at school and in society as a whole. The knowledge stored in their cognitive structure is assimilated by the individual according to their maturity, learning, and experiences (Vergnaud, 1990).

The author understands that a conceptual field is a grouping of problems, situations, concepts, structures, theoretical knowledge, and thought operations that are linked and dependent on each other. Concepts cannot be harnessed separately; therefore, an object of study requires a set of properties that are acquired through different situations. Thus, we designed our activities based on the definition of the situation proposed by the above-mentioned author, which refers to a set of tasks concerning a preestablished object of study for students to express as many operative invariants as possible linked to the conceptual field approached (Vergnaud,1990).

Operative invariants are key elements in CFT and can be divided into concepts and theorems in action. They are identified through the set of representations expressed by the students. This research combines the theoretical and practical concepts that comprise the conceptual field of water. It is from this perspective that teachers can guide their students to make these invariants explicit, developing new learning methodologies (Vergnaud, 1996).

To demonstrate how the operative invariants emerge in terms of the conceptual field of water, more specifically concerning our activities, students can apply the concepts of evaporation, precipitation, fusion, and condensation implicitly to explain the water cycle. These represent the concepts in action, through which student develop their ideas and the proposals that will guide their actions, in addition to the potential outcomes to be achieved in a given situation, which are, in turn, known as theorems in action.

According to Souza, Lara, and Moreira (2004), operational invariants are the link between theoretical and practical knowledge. In most cases, these concepts and theorems do not appear explicitly; therefore, the teacher must provide paths towards achieving them, and then manage the actions to be worked on in each situation based on them. Regarding the activities presented here, this link is established between the disciplinary knowledge of the hydrological cycle, also known as the water cycle, and the practical activity of physical state changes, so students can recognize the application of disciplinary knowledge in real everyday situations.

In the scope of teaching sciences, Moreira (2002) highlights the following interconnected key points linked to the theory of conceptual fields: theory, practical activities, and problem-solving. In the learning process, theoretical knowledge is shaped for the student from a set of situations that meet their experiences. Thus, such situations are established as teaching instruments as well as for the conceptualizing process.

From this point of view, by having the skills to work with a set of situations appropriately in terms of theoretical knowledge, students begin to develop a mental framework that will enable them to deal with further situations in similar contexts. This mental model will enable the student to take a more consistent approach to new situations, contents, and conceptual fields (Vergnaud, 1994).

In this perspective, we propose to analyze the operative invariants that emerged while developing interdisciplinary activities, based on the IIR methodology, guided by the following concrete problem: “How can the decrease in rainfall in Mato Grosso do Sul affect the supply of water that reaches our homes”?

METHODOLOGY

This study is based on a qualitative approach, which focuses on real situations that cannot be quantified, prioritizing the understanding of social dynamics. Qualitative research allows for the interpretation of representations attributed by participants to situations experienced in their own context (Creswell, 2010).

Considering our general objective – to analyze the potential operative invariants for the conceptual field of water as explained by the students while developing an IIR –, we highlight our choice for an interdisciplinary methodology to gather data for scientific concepts from different fields to be harnessed in the classroom. Thus, the analysis of the data gathered will allow us to understand how the students reached the disciplinary knowledge investigated.

The IIR methodology was developed in eight stages, as proposed by Fourez (1997), during which our target audience (EJA students) and specialists (researchers and teacher) interacted with each other. Based on this teaching and learning relationship, we sought to develop an IIR to harness scientific concepts about the conceptual field of water.

The IIR as a methodological route was designed in the scope of two EJA groups. The age group of the participants ranged between 20 and 60 years old, with 15 students having completed the activities as a whole. To ensure data confidentiality, the analysis of the results shows the students identified by the letter “S” followed by a number. Thus, “S1” refers to student 1.

The practical activities approached the concrete problem seeking to help the students to learn the scientific concepts covered by the desired object of study.

Below we introduce the three activities performed during the implementation phase: 1st - a discursive activity about changes in the physical states of water; 2nd – an investigative questionnaire about the song “Planeta Água” by Guilherme Arantes, and 3rd – an experimental activity about changes in the physical states of water.

The first activity introduced the students to a cartoon (figure 1) in which the character "Bidu", by Maurício Souza, observes water in its different physical states. Next, the students answered a question on the natural phenomena shown in the cartoon, as well as the scientific concepts involved. The following question was proposed: "In the cartoon, the character Bidu is "talking" to the water, what does the statement in the third comic illustrate and how would you explain the phenomena occurring in the water?"

Figure 1

Cartoon of the character Bidu interacting with water

Fonte: Maurício de Sousa 2004: https://www.researchgate.net/figure/Figura-1-Personagem-Bidu-observando-a-mudanca-do-estado-fisico-da-agua-Mauricio-de_fig1_341448035

The first activity was designed to help students express their preliminary knowledge, which could be based on common sense, as well as be able to relate the disciplinary knowledge of the change in the physical state of water to its applications in everyday life. This knowledge is directly linked to the hydrological cycle and has an interdisciplinary bias by encompassing knowledge relating to the disciplines of chemistry and biology.

For the second activity, the students watched a video of the song "Planeta Água", and then answered a research questionnaire aimed at detecting the presence and features of the different physical states of water in the lyrics, which emerged through concepts and theorems in action. In addition, the students answered the following questions: 1. "The song chorus says: "Earth, water planet". What does the composer mean by that? Do you agree with the chorus? Please, explain your answer."; 2. "In which part of the song does the composer show a change in the physical state of water? Could you explain how these changes occur?"; 3. "What other changes in the physical state of water do you know?", and 4. "Based on what part (s) of the song could we reflect on the benefits of water?".

This second activity aimed to use the lyrics of the song "Planeta Água" as a tool to help students explain as many operative invariants as possible relating to changes in the physical state of water, as well as how these changes interact with the hydrological cycle, meeting the concept of situation proposed in the CFT.

The last proposal encompassed a practical activity aimed at showing the phenomena of boiling, evaporation, fusion, and liquefaction. The practical activity covered the following three steps: the students heated two or three ice cubes in a beaker using a tripod with an asbestos screen and a heat source, through which they observed the change in the physical state that occurred in the beaker. Soon after, the students answered the following questions: 1. How would you explain what happened with the ice cube by contacting the heat source?"; 2. "What physical states of water are shown?", and 3. "What change in the physical state occurs in the experiment?".

Subsequently, they continued heating the water in a beaker until it boiled using a tripod with asbestos cloth and a heat source. They then answered the question: "What change of physical state can we observe at this stage?"

Finally, the students handled the beaker using a wooden clamp and then placed it on a surface after covering it with a Petri dish, thus observing the change in the physical state. Next, they answered the following questions: 1. "What change in the physical state occurs at this stage"; 2. "What is the relationship between the water droplets on the Petri dish and rain formation?", and 3. "What is the change in the physical state and what natural phenomenon allows the volume of water to rise in rivers and streams where water is captured to Supply our homes?"

The practical activity was designed to provide a link between the disciplinary knowledge of changes in the physical state of water and its applicability in real-life situations (Camilo and Graffunder, 2021).

Such a connection provides students with a more consistent and meaningful learning process. Thus, by applying this practical activity, we sought to compare theory and practice, according to Fourez (1997), and thus develop strategies that foster positive outcomes when facing the concrete problem proposed.

This practical activity showed interdisciplinarity through the integration of disciplinary knowledge related to chemistry with the change of physical state and the properties of water molecules in each state; in addition to biology, regarding rainfall, and thus the water cycle and its implications for the environment and society. Finally, physics was included in the discussion on thermal energy.

RESULTS

We analyzed the potential operational invariants that emerged from the representations described by the students in the three activities developed as part of the interdisciplinary project. We examined the transcripts of different students to identify the invariants shown. Some were able to express invariants appropriately in terms of the scientific concepts covered by the disciplinary knowledge underpinning the activities, while others managed to come close to what was expected. Regarding the invariants that diverged from scientific knowledge, actions can be redirected so that doubts or difficulties can be resolved later on.

The invariants identified were divided into the following categories: appropriate, relevant, and inappropriate. The categories were structured according to the scientific concepts to which they refer. It is also worth mentioning that we present the analysis for each of the three activities performed while building the IIR methodology individually.

Tables 1, 2, and 3 show the operative invariants identified in the discursive activity about changes in the physical states of water, the research questionnaire about the song "Planeta Água" by Guilherme Arantes, and the experimental activity about changes in the physical states of water. Table 1 contains the operative invariants that emerged in the activity on changes in physical states.

Table 1

Operational invariants observed in the discursive activity about changes in the physical state of water

Categories	Concepts in action	Theorems in action
Appropriate invariants	Vaporization	"Water in its liquid state evaporates to form clouds, the phenomenon of evaporation" (E3).
	Physical states of water	"The physical states of water are solid, liquid, and gas, each of which has its own characteristics" (E4).
	Fusion	"Ice in its solid state becomes liquid because of heat" (E5).
	Thermal energy	"Physical states can be altered by changes in temperature" (E4).
Relevant invariants	Precipitation	"The ice defrosts, rises into the atmosphere as vapor, and falls again in the form of rain" (E2).
	Vaporization	"The water becomes gaseous and turns into clouds" (E5).
Inadequate invariants	Vaporization	"The water is absorbed by the soil and goes into a gaseous state" (E1).
	Fusion	"In contact with the soil, the water becomes liquid" (E1).

Source: Elaborated by the authors, (2024).

Regarding the first activity, the category of appropriate invariants shows that students E3, E4, and E5 were able to explain theorems and concepts in action enough to approach scientific concepts linked to the disciplinary knowledge that covers changes in the physical state of water.

The relationships established by the students are consistent and agree with the research by Correia, Barros & Pereira (2020), clearly expressing the features involved in the phenomena of changing physical states, in which the students recognized the variation in temperature as key to the transition between the physical states of water. These representations shown in this category help to provide mental structuring of the link between theoretical and practical knowledge, which adds to the learning process based on the concrete problem.

Student E3 was able to express the transition between liquid water and the vaporization process, as well as identify that this process is linked to the formation of clouds. Student E4 explains the theorems in action that illustrate the physical states of water, as well as the need for temperature variation for the transitions between physical states to occur. In turn, student E5 demonstrates, through the theorem in action, that ice in a solid state changes to a liquid thanks to heat, approaching the disciplinary knowledge considered scientifically correct, in which there is a transfer of thermal energy between the water molecules and the environment, with the molecules starting to move more fluidly, favoring a change in their spatial arrangement.

Regarding the invariants considered relevant, the statements by students E2 and E5 suggest that they have understood the relationship between the disciplinary concepts, although this relationship is vague. For example, student E2's statement does not describe the changes in physical state from gaseous to liquid again in the process of rain formation.

However, teachers/researchers can use these relevant invariants to help students build more consistent representations of these concepts. This requires organizing new situations to encourage students to improve and restructure their operational invariants concerning the defined object of study. It is worth emphasizing that these situations, according to Vergnaud (1990), are new sets of activities which, in this project, refer to the proposed concrete problem. Such a scenario fits in with the IIR methodology, as new activities can be carried out in the other stages of development, including those that are more complex to solve any doubts that arise during the process.

The representations classified as inadequate operative invariants described by student E1 conveyed propositions that do not conform to correct scientific knowledge. Thus, these invariants do not contribute to working on the concrete problem defined. In other words, these theorems in action deviate from the theoretical knowledge that underpins the concrete problem that guides all interdisciplinary action.

Table 2 shows some of the operative invariants that emerged in the second activity, which consisted of an investigative questionnaire about the song "Planeta Água" by Guilherme Arantes.

Table 2

Operative invariants observed in the research questionnaire on the song "Planeta Água" by Guilherme Arantes

Categories	Concepts in action	Theorems in action
Appropriate invariants	Vaporization	"Water evaporates, it goes from a liquid state to a gaseous state." (E6)
		"Water goes from a liquid state to a gaseous state." (E8)
Relevant invariants	Solidification	"When you put water in the freezer, it turns from a liquid to a solid. Water turns to ice in the freezer". (E6)
	Condensation	"Clouds are water in a gaseous state." (E9)
Inadequate invariants	Vaporization	"The water that the sun evaporates turns into clouds". (E7)

Categories	Concepts in action	Theorems in action
		"The sun evaporates the water that goes to the sky." (E6)

Source: Elaborated by the authors, (2024).

For the second activity, the students answered a research questionnaire based on the song "Planeta Água". Based on the diagrams provided, we found that students E6 and E8 were able to identify and adequately associate the features that mainly encompass the concept of vaporization.

As for the invariants considered relevant in this activity, we highlight the statements made by students E6 and E9. Student E6 associates the transition from liquid to solid water with the freezer. However, although a little incoherent, this theorem in action could be used as a starting point for the student to stop associating this change in the physical state of water with the freezer, and to start associating it with the oscillation of thermal energy taking place, which can be expressed by the temperature.

Student E9 manages to interpret that the phenomenon of vaporization is key to the formation of rain. However, he was unable to explain that clouds are water droplets that condense once the water vapor comes into contact with the air at a lower temperature in the atmosphere. This theorem in action expressed by student E9 is relevant as it provides substantial insight to be worked on and further developed in new situations. This invariant is not incorrect as a whole, it just needs to be worked on so that it approaches scientifically correct disciplinary knowledge more closely.

Students E6 and E7 scored inadequate invariants, as they were unable to correctly characterize that it is not precisely the sun that causes water to evaporate, but the energy that comes from it, as well as other means that can cause water to transition from a liquid to a gaseous state.

It is worth pointing out that even if they are inadequate, these theorems in action can evolve into adequate scientific concepts since, over time, the student's cognitive structure organization based on representations related to the object of study becomes more consistent, leading to the progression of more complex knowledge and an advance in the study of the conceptual field (Souza et al., 2004).

Table 3 shows the analysis of the operative invariants of the last activity developed for this project, which involved a practical activity about changes in the physical states of water.

Table 3

Operational invariants observed in the practical activity on changes in the physical states of water

Categories	Concepts in action	Theorems in action
Appropriated invariants	Vaporization	"The sun heats rivers, seas, and lakes, causing water to evaporate and form rain clouds." (E10)
	Condensation	"Water in a gaseous state changes into a liquid." (E14)
		"Water changes from a liquid state to a gaseous state." (E12)
Relevant invariants	Fusion	"The temperature heats the ice cubes, which melt". (E10)
	Precipitation	"The water in rivers and seas goes from a liquid state and evaporates into rain". (E11)
	Vaporization	"There's a transition, the sun heats rivers, seas, and lakes, and they evaporate, turning into rain." (E12)
	Precipitation	"Water passes from a liquid state to a gaseous state, forming the rains that fill rivers and lakes." (E13)
Inadequate invariants	Vaporization	"It goes from solid to liquid and evaporates". (E11)
	Precipitation	"The heat warms up the clouds and the water returns to its liquid state" (E15).

Source: Elaborated by the authors, (2024).

Completing the analysis of operative invariants, the last activity consisted of a practical activity on changes in the physical state of water. Based on the information gathered, the students showed considerably more adequate and relevant invariants than inadequate ones. Students E10, E12, and E14 correctly demonstrated, through theorems and concepts in action, the influence of solar energy on the evaporation process, as well as correctly describing the transition between the physical states of water.

Regarding the invariants considered relevant, we highlight the theorems and concepts in action shown by students E11 and E13, as they managed to identify that changes in the physical state of water from liquid to gas can lead to the formation of rain. However, these statements should approach scientific concepts relating to disciplinary knowledge about rain formation, such as the

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processes of condensation and precipitation, which were not addressed by the students.

As for the invariants considered inadequate, teaching strategies can still be revised to rethink these representations, which are part of the student's mental model. Throughout the other stages of the IIR, the scientific concepts demonstrated here can be approached together with the help of specialists to make them clearer and more meaningful to the student. According to Souza, Lara, and Moreira (2004), operative invariants have a direct influence on relating theoretical knowledge to real situations, thus, exposure to these new situations will promote the change or continuity of these concepts and theorems in action.

In this context, according to Costa et al. (2020), when developing IIR using practical activities, the learning process can focus on all the invariants that have emerged during the activities, both to strengthen them and to rebuild them in the case of inadequate invariants. For this process, working together with experts tends to be a successful way for students to consolidate this knowledge.

The implementation of IIR in the EJA context proved to be a distinctive methodology for promoting an inclusive learning process adapted to the diverse realities of the students. The IIR allowed for the strengthening and reconstruction of operative invariants, thereby enhancing the development of knowledge among the students.

The challenge of applying IIR to two EJA classes was both demanding and enjoyable. As a teacher and researcher, the need to create activities that reached a heterogeneous audience of students aged between 20 and 60 inclusively required innovative strategies and constant methodological adaptation. These unique educational approaches may emerge as a result of EJA students having different levels of maturity and life experience (Silva and Pereira, 2019). Such heterogeneity demanded special attention to ensure that theoretical knowledge was linked significantly to the students' reality, thus enabling the reconstruction of inadequate operative invariants and strengthening the relevant ones deployed while building the IIR.

FINAL REMARKS

This study highlights the contributions of practical activities based on an interdisciplinary approach to the development of an IIR about water. This research allowed for a broader understanding of the scientific knowledge related to the object of study, especially once grounded in real-life situations. Introducing interdisciplinarity in the EJA can pose rather unique challenges, such as the diversity of students' ages, experiences, and skills.

The general aim of this study was to assess the potential operative invariants of the conceptual field of water as explained by the students while developing an IIR, based on the following concrete problem: "How can the decrease in rainfall in Mato Grosso do Sul affect the supply of water that reaches our homes?". Thus, we were able to develop activities that represented and integrated the disciplines of chemistry, physics, and biology. We chose not to separate the activities by discipline, but to work on the disciplinary knowledge so that they were present and in consonance with each other, enabling the students to grasp the concepts referring to the conceptual field of water and achieving the proposed objective.

Thus, even faced with the obstacles posed by the implementation of the research, such as the challenges raised by the participating public, we were able to demonstrate that the IIR methodology proved to be a very efficient tool for enabling students to express as many operative invariants as possible about the conceptual field of water, as well as for these invariants to reveal different relationships between concepts about the defined object of study and the disciplines of chemistry, physics, and biology.

Our findings lead us to assume that the activities carried out helped students connect disciplinary knowledge with experiences in their own context. This highlights the importance of aligning teaching with the reality of EJA students, enabling them to learn in a way that is more meaningful and relevant to their lives. By analyzing these invariants, based on the theory of conceptual fields, we found that the students showed signs of mastery consistent with a scientific understanding of the conceptual field of water, answering the research question outlined in this project.

In the case of the EJA, progress was achieved throughout the implementation of the activities in terms of developing the students' skills to deal with the concrete problem. However, it was challenging to design activities that reached all the diverse backgrounds of the students who comprised the target audience. There were, for example, older students who had been out of the classroom for more than two decades, and our concern was that everyone should be able to grasp the proposed knowledge.

Finally, it is crucial to stress that by implementing these activities, the researchers show their eagerness to ensure that new teaching strategies, in addition to the ones they have developed, reach classrooms in a practical approach, as well as students from different contexts and backgrounds. The challenges experienced in the school environment can often be intimidating, but living the experience of implementing research with those for whom it was designed, planned, and developed, even in the face of so many obstacles and unpredictability in a classroom, only makes it more robust.

NOTES

1. This research follows the parameters established in CAAE No. 51736121.9.0000.0021, having been approved under Opinion number: 5.115.481
2. This article was originally written in Portuguese by the researchers and translated into English by professional translator Ivy Gobeti, who specializes in scientific writing.

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