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# The Interdisciplinary Approach of the Content "Transformation of Energy" in High School

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**Abstract**

The professional high school by the federal schools in Brazil requires an integrated curriculum itinerary. There is a lack of information about how to achieve that in a practical conception of integration. This article aimed to investigate the interdisciplinary approach of the content "transformation of energy" involving the relationship among Science, Technology, Society, and Environment (STSE) in integrated high school. The applied research procedure was a pedagogical intervention in which research subjects were the third year high school students, integrated into the technical course in food (n = 36) at the Federal Institute of Rio Grande do Norte, municipality of Pau dos Ferros, Brazil. The process of planning, execution, and evaluation of the interdisciplinary teaching sequence was carried out by teachers and researchers from different areas i.e., forest engineering, chemistry, phisycs, and physical educational. The data were compiled and evaluated through thematic analysis. The results showed that interdisciplinary learning favors scientific and environmental literacy, conceptual changes, expanded discussions, and the integration of the curriculum.

**Keywords:** professional education, teaching sequence, socio-scientific issue, critical environmental education, physical education, integrated curriculum

## 1. Introduction

The search for innovative pedagogical practices that can integrate the knowledge from different disciplines and overcome the fragmentation of knowledge has proved to be challenging in the educational field. Interdisciplinarity emerges as an approach capable of transcending disciplinary boundaries by promoting an integrated, deep, and meaningful vision of learning (Luck, 2013; Fazenda, 2018). From an integrative praxis perspective, critical environmental literacy should mobilize diverseknowledge about environmental conservation and enable an expanded and holistic view, as proposed by Freire's environmental education. In this context, interdisciplinarity emerges as a catalyst strategy of the teaching and learning processes in the interaction between the sociocultural dimensions with which the content can be approached (Dickmann & Ruppenthal, 2017; Fazenda, 2008).

The analysis and interdisciplinary discussions of controversial topics currently point to the relevance of socio-scientific issues (SSI) in teaching for stimulating the development of a critical scientific literacy by explaining the relationships between STSE in solving socio-environmental problems and contributing to the formation of engaged and politically responsible citizens (Conrado & Nunes-Neto, 2018). For Bazzo et al. (2003), the vision of a more comprehensive education is shown as a critical and structured alternative to the reductionist conception of traditional education when aligned with contemporary demands and the STSE movement. Thus, scientific literacy proves to be a booster of meaningful education as it considers the STSE approach and provides a better reading of the world through science (Chassot, 2018). Interdisciplinarity must be understood beyond the meeting of disciplines. It is the meeting of individuals, who form partnerships in the construction of an interdisciplinary proposal. This proposal aims to consolidate a dialogue with other forms of knowledge to which they were not accustomed by acting with rigor, authenticity, and commitment in the execution of an intentional project that seeks to transcend institutional limits by contributing to the development and social formation (Fazenda, 2003).

Education can be a tool of political liberation, which has the opportunity of generating a critical, transformative, and differential consciousness in an emancipatory pedagogical practice. This awareness foreshadows a new

education for the future, the culture of silence, and the contradictions of banking education in the transmission of knowledge (Freire, 1967, 1996, 2016; Morin, 2000). Therefore, teachers play a crucial role in mediating teaching and interaction, which is in line with the sociocultural theory of learning (Vygotsky, 1991).

Saviani (2021) and Tiriba (2021) confirmed that the critique of the current educational system is that it focuses primarily on the content of study and not on the intelligence, creativity, and solidarity, which are necessary for a full human existence. Both studies highlight the contradictions in the current pedagogical proposition. Saviani (2021), for that matter, emphasizes the need to cultivate not only the transmission of scientific concepts but also the integration of the contents of the disciplines with other areas of knowledge. In addition, education must overcome the development of technical skills to contemplate a comprehensive perspective in the formation of critical citizens, who are able to analyze and propose solutions to social challenges (Conrado & Nunes-Neto, 2018).

Research in teaching areas has consistently sought to innovate methodologies and strategies to promote contextualized pedagogical practices that arealigned with the planetary era. In this context, the interdisciplinary teaching sequence (ITS) proposes the integration of knowledge by stimulating the critical thinking of teachers and students in the school environment and beyond. This approach enables the orderly structuring of sequenced activities to achieve specific educational objectives by exploring the importance of different dimensions of knowledge (Zabala, 1998; Morin, 2000).

The teaching sequence structured by Zabala (1998), which adds multiple types of knowledge anchored in a STSE perspective, meets the concept of integrated high school (IHS). Since it enables a cohesive pedagogical approach, which thinks beyond the integration of content, providing cooperative learning in line with the dimensions of work, science, technology, and culture (Frigotto et al., 2005). The role of the teacher in the integration of global social practice into educational practice is emphasized as a fundamental contribution to the process of social transformation (Saviani, 2021).

Consequently, work as an educational foundation must be analyzed under the aegis of an ethical-political principle that is inseparable from social practice, as highlighted by Frigotto et al. (2005) and the curricular guidelines for technical professional education of secondary level (TPESL). Work as an educational principle, proposed by the TPESL, points to the omnilateral and integral formation of the individual, which is contrary to unilateral. This perspective prepares individuals not only for the job market but also for active participation in society. Thus, it is imperative to consider interdisciplinarity in the curriculum and pedagogical practice, aiming at overcoming the fragmentation of knowledge and segmentation of the curricular organization (Brazil, 2012).

This article aimed to investigate the interdisciplinary approach of the content “transformation of energy” from a STSE approach within the integrated high school. This focus was articulated by the knowledge of the areas of physical education, chemistry, physics, and environment science, with a focus on critical learning and connection with socio-scientific issues.

## 2. Method

This study was configured as a qualitative research of an applied nature with descriptive and explanatory objectives and procedures of the pedagogical intervention type (Damiani et al., 2013). The research was conducted through an investigation of pedagogical practice that included the phases of planning, development, and evaluation of an ITS with the integration of knowledge from the areas of chemistry, physics, physical education, and environment from the STSE approach.

### *2.1 Participants and Sample*

The ITS was planned following the assumptions defined by Zabala (1998) and the application occurred in the first semester of 2024 in a group of 36 third year high school students integrated in the technical course in food at the Federal Institute of Rio Grande do Norte, campus Pau dos Ferros city, Brazil. The ITS execution process took place in partnership with a physicsteacher (who was the group teacher), a chemistry teacher, a physical education teacher, and a forest engineering teacher. During the planning phase, it was decided to address a theme contemplated in the physics curriculum whose theme was generated by an SSI. We formulated the following problematization: how could the content “transformation of energy” be integrally approached under the STSE perspective and still favor a critical and contextualized learning? This study was approved from the research ethics committee of University of the State of Rio Grande do Norte, Brazil (No: 78775724.0.0000.5294)

ITS application time was three weeks with a total of six-hour lesson: a two-hour lesson for the approach of initial concepts about the environment and clean energy (Stage 1). Another two-hour lesson for the approach on the transformation of energy in the environment and the human body (Stage 2), and a two-hour lesson for the practice on energy expenditure by the human body in physical activity (Stage 3), as can be seen in Table 1.

Table 1. ITS's Planning Synthesis

| Stages and description | Objectives | Duration |
|---|---|---|
| **Stage 1 (Introduction):** Dynamics of presentation, conversation circle on the environment and clean energy with a STSE approach.<br>**Diagnostic assessment**: questionnaire. | To critically analyze the environment and the MFC (Microbial Fuel Cell) as clean energy technology.<br>To verify prior knowledge about the different types of environments. | two-hour lesson (90 minutes) |
| **Stage 2 (development):** Lectures involving the knowledge of chemistry, physics, and physical education on the types of energy, and transformation of energy in the environment and the human body.<br>**Diagnostic assessment**: questionnaire and observation. | To differentiate the types of energies and their transformation in the environment and the human body. To discuss the impacts of the implantation and operation of wind power plants in the Brazilian northeast. | two-hour lesson (90 minutes) |
| **Stage 3 (conclusion):** A physical education practical class about energy expenditure by the human body and the importance of collective physical activity.<br>**Final assessment**: questionnaire. | To collectively exercise the body, verifying energy's benefits and how the human body processes this energy through a Tabata circuit. | two-hour lesson (90 minutes) |

### *2.2 Data Collection and Analysis*

Participant observation and questionnaire were used as a data collection technique. They were applied at the beginning and at the end of the ITS with open questions that integrated the different stages of planning. The answers served as the basis for the construction and analysis of the results achieved in the research. The students were divided into nine groups with four members each, where they could expose in a written form their perceptions of environmental representation, clean energy, interdisciplinarity, and collective benefits of the promotion of outdoor physical activity. The answered questionnaire was delivered after the evaluation of stages 1 to 3.

Data analysis was made from the technique of thematic analysis (TA) proposed by Braun and Clarke (2006). The authors defined the TA method as systematized in six stages, as shown in Figure 1.

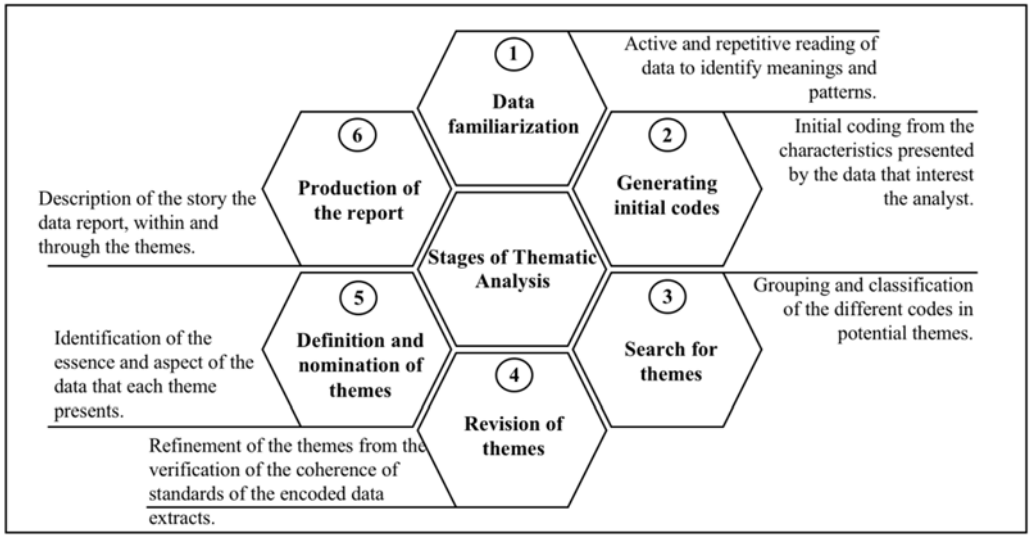


Figure 1. Stages of thematic analysis

## 3. Results

ITS was planned to integrate the knowledge of the areas of physical education, chemistry, physics, and environment science in the approach of the content "transformation of energy" from a STSE emphasis (Table 2).

Table 2. Learning objectives on the transformation of energy content

| Area | Content | Conceptual dimension | Procedural dimension | Attitudinal dimension |
|---|---|---|---|---|
| Environment Science | Clean and renewable energy | Concept of environment and bacteria producing electricity | MFC experiment about infinite energy Mudwatt® kit | Social representation in the environment |
| Physics and Chemistry | Energy and transformation | Concepts of types of energy and their transformation | Simulator on the transformation of energy | Discussion on the impacts of wind power plants |
| Physical Education | Energy and the human body | Concepts on bioenergetics(ATP production) | Percentage of the calculation of heart rate (HR) | Collective practice in Tabata circuit. |

The learning objectives of the content presented in Table 2 went through the three dimensions proposed by Zabala (1998) and Conrado and Nunes-Neto (2018). We choosed the approach of a controversial topic as a SSI which was the transformation of energy and the wind power plants. The study intended to provide students with the moments of reflection from elements brought from everyday life and their relations with the community, which is called the reading of the world by Freire (1988) and Chassot (2018). These readings helpeded the students to better understand the impacts of the construction and operation of wind power plants in Brazil, especially in the northeast region, more specifically in the state of Rio Grande do Norte.

The spontaneous knowledge raised during the execution of the ITS allowed the students to question how a technology commercialized as clean and/or renewable (wind energy) can still be criticized. These issues sought to encompass not only economic but also social, environmental, ethical, political, and cultural aspects by anchoring the SSI theme under the holistic perspective of the STSE movement. It attempted to transcend a reductionist to a scientific and technological literacy (STL), reaching a broader view on the subject (Kauano & Marandino, 2022).

In an attempt to capture nuances with the application of ITS, moments of debate and reflection were proposed to students, who were evaluated continuously throughout the sequence execution process. In this sense, the formative evaluation was the chosen assessment instrument, because it involved the confirmation of learning throughout the learning process and execution of activities at each moment.

In regards to evaluation, both, the teacher and the student, could monitor the level of learning and modify it if necessary. This evaluative strategy should be anchored in the proposed objectives and be focused on learning and evaluating conceptual, procedural and attitudinal dimension (Carvalho, 2013).

### *3.1 Stages of ITS Application*

The classes related to the stages of ITS application were taught by the teacher and researchers responsible for each area mentioned in Table 2. Each of them contributed according to their expertise. Initially, we received and led by the physics teacher to the classroom, where the convergence of contents had already begun. The desks were arranged in a circle and we performed a dynamic interaction with the class, in which students and teachers could present themselves in order to establish a greater familiarity and connection in pairs. After the dynamic interaction, the ITS was presented and the students were invited to collaborate in the formulation of the social representation of the concept of environment in written form with the subsequent socialization of the answers. After this diagnostic assessment and with the feedback received, there was a discussion about the multiple conceptions of the environment to change the conceptual profile. Then, the aspects of the STSE movement were briefly discussed concerning the processes of transformation of energy. On this occasion, we talked about the macro-trends or aspects of environmental education and clean energy with the use of the Mudwatt® kit. As a result of the diagnostic assessment, we presented the formulation of themes after the coding and analysis of answers from students. The social representation of the concept of environment was conducted according to Reigota (2013). Excerpts are presented in Table 3.

Table 3. Social representation of the concept of environment

| Themes | Answers from students |
|---|---|
| Naturalist | "Group of natural elements, air, water, soil, flora, fauna […]"; |
| | "What has the green color […]"; |
| | "[…] space where there is life". |
| Anthropocentric | "Group of ecosystems modified by the human being"; |
| | "[…] It is structured by the actions of the human being"; |
| | "[…] man interfering in the local environment". |
| Globalizing | "[…] an important place for the culture of different peoples […]"; |
| | "[…] a space-society relation"; |
| | "[…] a pillar for economic growth". |
| Multiple approach | […] man-nature interaction |

Conceptualizing the environment is not an easy task since each representation developed by the individuals occurs through a unique and/or collective perspective of the world that, under a social aspect, may equally contribute to the explanation of social and environmental issues (Reigota, 2013). In this research, we did not intend to define the multiple definitions of the environment since we believed that the elements brought along and discussed throughout this study already contribute to the formation of a personal and disruptive concept of the environment.As expected, the perspective of the environment presented by the majority of students was shallow and reduced concerning theoretical aspects that focus on STSE. Some answers contemplated more than one theme, which maybe acceptable due to the complexity of the establishment of the environmental concept. This proved that the themes are dynamic and there are numerous possibilities of analysis and the convergence with other approaches and perspectives about the environment. In Table 3, we noticed the predominance of answers that indicated an idealizing perspective of the environment, which was reinforced by the natural representations of the preservationist and biological spaces, with little or no connection to the territorial spaces, lived and occupied by the students themselves in an interaction that is processed throughout their lives. We concluded that such elements wereabsent not due to the lack of student knowledge, but due to the lack of criticism and stimuli that led them to the formation of a decolonial vision in the deconstruction of restricted or exogenous patterns around the conceptualization of the environment.

The second moment of ITS application took place through an expository chemistry lecture, where important aspects were addressed on the theme "transformation of energy". During the class, the concepts of transformation of energy were discussed. They were presented in the content of physics and their connection with the teaching of chemistry. The students were engaged in participating in the discussions by demonstrating that they already had some knowledge about the subject, probably acquired at some point in their school trajectories. The critical sense shown by some of the students was also striking as they were familiarised with the types of renewable and non-renewable energy and their respective characteristics.

An important and debated aspect of this class was the usage of wind energy as an energetic alternative for making a greater thematic contextualization possible since the state of Rio Grande do Norte presents itself as one of the main producers of this type of energy in the country. This state stands out as the second federacy that produced the most wind energy in 2022 (ABBEólica, 2022). There are many factors that necessitate the search for an energy source that either has no negative impact on the environment or has minimal impact when such impact is unavoidable. However, in addition to exposing the positive aspects of the implementation of a wind power plant, students were encouraged to report some negative aspects of that projects in the region. The alteration in the local landscape, noise pollution (mainly for people and animals that live around the power plant), migratory flow of birds and other animals that live in the location were among the disadvantages raised by the students. In this exposition of opinions about the negative aspects, one student's speech was marked when he reported: "I once heard a story that some residents were acquiring health problems due to the noise of the propellers". The student's speech met one of the methodological proposals of the ITS, which was a video presentation of a reporting story that brought testimonies from local residents about the disorders caused by the noise of the propellers and skin problems, which, according to them, were acquired due to the exposure to the raw material that served for the production of the propellers of the wind turbines. However, the video was not presented due to technical problems with the internet connection. It was only exposed orally by the regent teacher, complementing and evidencing the student's speech. Once the positive and negative aspects of the implementation of a wind power plant were discussed, we finished the class by highlighting the application of the concepts of transformation of energy. For this, we simulated the learning object "Forms and Transformation of Energy", which was available in the repository of virtual simulations "Phet Colorado" (https://phet.colorado.edu/pt_BR/). During the simulation,

students were able to identify which types of energy were associated with the production of wind energy as well as to realize the main differences in the types of energy approached.

The physical education class presented itself as the third stage of ITS application. It was developed with the proposition of alignment with themes previously approached in earlier moments. The interdisciplinary character became evident by relating the production of energy in the human organism to metabolic processes and the production of energy systems in the environment. The MFC experiment, previously introduced by the forest engineering professor, also found its place in this narrative.

The culmination of the interdisciplinary learning experience was the transition to the practical outdoor class, where we applied the Tabata training. This methodology not only illustrated the physical and mental changes that resulted from the exercise, but also provided a tangible view of how the areas from the ITS can share knowledge in the pursuit of integrated, meaningful, and profound teaching. The collective action emphasized the potential of interdisciplinarity as most students engaged in the same perspective and respected their singularities.

Despite efforts to create an inclusive experience, one student chose not to participate, mentioning knee joint discomfort. This resistance revealed challenges and issues that need to be considered in future pedagogical practice, emphasising the importance of ITS flexibility and adaptation. Before practical performance, the origin of the Tabata training was explained. It was accompanied by the measurement of the heartbeat and the calculation of the maximum heart rate (MHR), which contributed to a deeper and more critical understanding of the physiological impacts of the exercise.

When we returned to the classroom, the post-practice discussion enriched because, in addition to analyzing the responses of students before and after the exercise, we explored the constant interrelationship between the knowledge and the socio-environmental issues involved in the moments of the activities. The discussion extended beyond the physical scope addressing the potential environmental impact of physical activities and fostering reflections on nature conservation.

In this direction, the ITS application not only met the objective of integrating disciplines but also provided a critical and contextualized educational experience. This report showed the relevance of interdisciplinary approaches to a more holistic learning and the importance of adaptability and continuous reflection in the teaching and learning processes.

The coding of the data and the mapping of the themes were presented from a reflexive thematic analysis of the answers presented by the students after the evaluation of the activities carried out in stages 1 to 3 (Table 1). Once the answers were formulated in groups, we referred to each of them through an alphanumeric coding, from G1 (Group 1) to G9 (Group 9). The codes and themes of analysis were indicated through thematic maps created after the evaluation of the ITS research method. Figure 2 depicts the final thematic map of the assessment of stages 1 to 3, presenting schematically the themes and codes of analysis identified with the execution of the TA stages proposed by Braun and Clarke (2006).

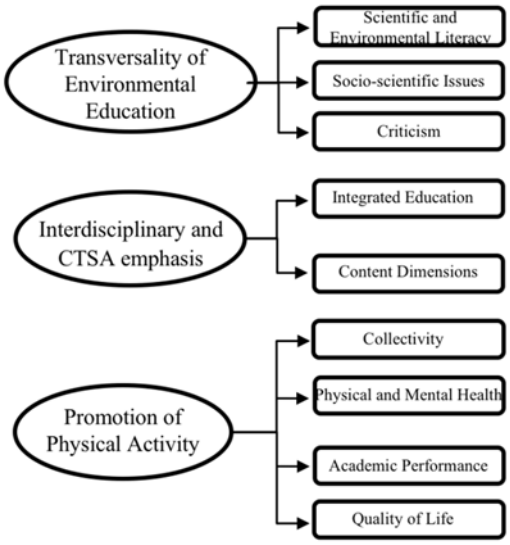


Figure 2. Final thematic map of the assessment

## 4. Discussion

### *4.1 Transversality of Environmental Education*

During the reflective analysis of the students' responses, it was possible to perceive the presence of aspects related to environmental issues, especially concerning environmental conservation. G3 reported the possibility of using alternative sources of clean energy, showing evidence of the existence of environmental literacy of students, which may have been developed during the academic trajectory, but reinforced by the ITS application.

In turn, G8 highlighted the positive and negative aspects of energy production in Brazil, evidencing the strong presence of criticism as a fundamental element. Thiscan be evaluated as an important characteristic in the development of environmental and scientific literacy among students. Loureiro and Torres (2014) argued that the personal development of criticism is crusial, highlighting that the transformative character that they can exercise in society through an academic education that makes these subjects able to critically interfere with the reality that surrounds them.

Another relevant aspect evidenced in the analysis was the relationship that students were able to make between the theme "transformation of energy" addressed in the ITS and the SSI. This was perceived when G8 reported on the problem of environmental degradation as one of the negative points in the implementation of wind power plants. Besides explaining the presence of criticism in students, this aspect also corroborates the idea that themes that have an impact on social discussions can and should play an important role in the development of a CEE.

Dionor et al. (2020) emphasized the importance of the use of SSI in the context of teaching and learning due to the possibilities that socio-scientific issues offer for the establishment of a training process that can form socially and environmentally responsible citizens. In addition, Conrado & Nunes-Neto (2018) pointed out the content approach in inter and multidisciplinary manners as one of the relevant characteristics of the use of SSI in understanding scientific knowledge as a fundamental factor in the search for solutions to the most varied types of problems.

Thus, we consider the use of SSI as a relevant tool to develop an environmental education, capable of forming and transforming critical citizens who demonstrate in their thoughts and attitudes a desire to positively modify the reality to which they belong.

### *4.2 Interdisciplinarity and the STSE Emphasis*

The integrative proposal that supported the development and application of ITS showed relevant results regarding the students' perception of interdisciplinarity. For the report, G2 used the approach of the same theme in different contexts, which provided an expanded view of a content, contradicting compartmentalized teaching.

Students' perception corresponds to s what Luck (1994) sees as one of the objectives of interdisciplinary pedagogy. The author understands that interdisciplinarity is presented as a possibility of overcoming the dissociative aspect of school experiences faced by students. In the present study, the integrated aspects were related to the unifying character of the disciplines from a theme of recurring importance in the debates related to the environmental education, the processes of production, and transformation of energy.

The interdisciplinary perspective of the contents emerged as a starting point for the development of teaching practices that seek the integration of different types of knowledge. Silva et al. (2020) affirmed that interdisciplinarity serves as a facilitating element in the integration of different areas of knowledge. This enables the interaction between science and an innovative approach to specific content, which can dynamise the teaching and learning processes.

In the context of human formation, integrated education seeks to give individuals the right to holistic training, which leads them to the acquisition of a reading of the world so they can understand the social relations underlying all phenomena (Frigotto et al., 2005). This premise reinforces the idea that pedagogical practices sustained through the perspective of integrated education contribute to the development of citizens who able to perceive, think, and act in the most varied contexts of the dynamic society in which they live.

Another aspect that emerged from the analysis was the identification of elements that allowed us to relate the responses of the students with the learning objectives of the ITS and the dimensions of the contents. G1 related the theme "transformation of energy" to notions of "balance/stability", "strength and power", "exothermic reactions" and "sustainable and alternative energies". G6 mentioned the terms "friction force", "weight force", "metabolism", "cardiac system", "metabolism chemistry" and "energy". These concepts were already studied in the discipline of physics that could be treated in an integrated manner.

The comments students made to certain concepts during the ITS application attest that the conceptual dimension

of the contents was present during the learning process. Conrado and Nunes-Neto (2018) emphasized that the understanding of concepts is only achieved at the moment when students can mobilize them in concrete situations, in which they are needed. From this perspective, we believe that the understanding of concepts became transparent in the various moments in which students socialized their perceptions and understandings about the theme, adding to the procedural and attitudinal dimensions of the ITS (Table 2).

*4.3 Promotion of Physical Activity*

From the analysis of the final thematic map (Figure 2), we noticed a positive and articulated association with the promotion of outdoor physical activities that explored the sense of collectivity in connection with the production of energy by the human body. This was evidenced when G1 confirmed that collective work between social groups is better than work individually. At the same time, the coexistence between diverse groups (social, cultural, economic, ethnic) can be facilitated by the promotion of outdoor exercises. This report demonstrates the contribution of the STSE approach to the expanded vision perceived by students at the end of the practice.

Collectivity was found to be associated with group productivity. This is consequently linked to the expenditure of energy by the human body, which contributes to the improvement of "school performance" (G2). In this aspect, we observed that students performed an intrinsic relationship between socialization and the construction of an interdisciplinary learning process guided by the ITS by recognizing that integration is a driving tool for collective learning and meaningful exchanges of experiences, which is in line with (Behrens, 2011), sharing the understanding that bioenergetics would be the booster of this process.

In addition, we observed that the notion of collectivity appears intrinsically linked to the ideas of "social integration", "increased sociability", "promotion of social interactions" and "greater socialization […]", reported respectively by G1, G2, G3, and G8. These similar statements show the effective defense that the exploration of the diversity of school spaces expands the possibilities of interdisciplinary learning. These excerpts above are directly related to the place chosen for the practice of physical activity. This place represents open and enclosed courtyards, which are traditionally not used for sports despite being part of the school building structure but proved to be a place of creativity and more dynamic learning.

From the perspective of an interdisciplinary approach, it is important to say that the diversity of contents worked with integrated high school is a stimulus to integral training and to overcome contradictions that still exist concerning the organization of the curriculum. This transcends beyond the positivist perspective of compartmentalization of knowledge, increasing the significance, synergy, and integralization of the objects studied (Frigotto et al., 2005). It is noticeable that one of the most imperative aspects of this interdisciplinary approach is that the (re)construction of knowledge must transcend the limits of classrooms by crossing all spheres of students' lives as advogated by Freire (2016). This creates a relevant significance for shared content and knowledge built within and outside the school walls. In an education guided by interdisciplinarity, Pombo (2005) reinforced that the disciplines overcome the limitations that separate them and unite them into something higher that transcends all. It creates new meanings for diverse contents, which may become a deep experience for students confirmed by Zabala (1998) findings.

Concerning the topic of physical and mental health, the research subjects go beyond physical health only by highlighting the results and benefits of outdoor activity for collectivity: "It is good to control anxiety" (G6), and "increases self-esteem" (G7). We pointed out the fact that students are part of a generation that experienced the coronavirus pandemic during early adolescence, a period in which social isolation was striking and necessary. Therefore, we can infer that the ability of association between outdoor physical activity and mental health is a knowledge experienced by this generation, and perhaps this is why it was often mentioned in the speeches.

Students also talked about t the relevance of closer contact with the natural environment as a fundamental element to achieve a significant improvement in the quality of life. G5 exemplified this benefit by stating that the practice of outdoor exercise would make people more active, increase school performance, and show the interconnection between individual well-being and intellectual performance.

During physical activity, more specifically in the final stage of ITS application, cooperation among groups emerged spontaneously through the execution of the Tabata circuit. The students worked together in the execution of movements and in the manual measurement of heart rate. This scenario aligns with the perspective of Zabala (1998) on the relevance of working the contents in a meaningful manner so that students can connect them to their own life experiences. As a central conception, the author defends the priority of knowledge related to life as a primordial element in the disciplinary contents.

Students' answers demonstrated the feeling of belonging and the recognition of the positive impacts that regular

exercise can have in the promoting collective health through social relations and the relationship with the environment. Therefore, the educational approach with well-defined learning objectives not only enriches the understanding of the interrelationship between disciplines and life but also consolidates an integrated perspective within the educational context (Zabala, 1998). When experience allows the subject to recognize itself and to be positively affected, it becomes significant (Freire, 2016). Furthermore, individual experience expands the spectrum of opportunities that content presents, offering a greater potential for developing critical self-awareness, understanding others, and comprehending the world (Saviani, 2021). The groups' performance in the activities resulted in an important and dynamic cooperation that favored the participation of students, which also can reverberate in extracurricular experiences corroborating with the studies of Matos (2012).

Interdisciplinarity in the integrated high school is approached punctually by Lima (2021), who developed a model of integration among different areas of knowledge in the promotion of a critical environmental education through a pedagogical trekking in Amazon region. The trekking, highlighted in Lima's research, presented itself as an enriching pedagogical practice making the combination of theory and practice possible in the teaching of diverse contents and the integration of knowledge of physical education, geography, biology, and history.

The view on interdisciplinarity is widely shared and being used as a way to overcome the fragmentation of disciplines (Pombo, 2005). The perspective presented in the integration of disciplines is meaningful for everybody involved in the educational process. The practice of outdoor physical activity, when explored as a pedagogical tool, enables this integration, providing a more holistic and contextualized approach to learning (Lima, 2021).

The disruptive classroom can provide practical and immersive experiences for students, especially in the context of the integrated high school. Thus, in convergence with Vygotsky (1991), who understands that human development is the result of social and cultural interactions and that learning must occur effectively through participation in mediated activities.

The teaching of physical education in Brazil has historically been influenced by the values of competition. For many years this discipline was approached in a reductionist form as reported by Bracht (1992) and Corrêa and Lima (2023) with the content that valued only the work with the body in a biological way, not taking into consideration body practices as cultural manifestations, which are influenced by the cognitive, social and behavioral development of human beings. Corrêa and Lima (2023) pointed out that scientific evolution helped to modify this simplistic view, which lead to the awareness that it is a discipline that can work diverse contents through bodily practices, which contemplate the various dimensions of the human being (biological, anthropological, sociological, psychological, philosophical and political).

## 5. Conclusion

The articulation of multiple knowledge in the areas of physical education, physics, chemistry, and the environmental science was more than a meeting among disciplines of the integrated high school. First, it occurred through a meeting among individuals, which transcended beyond a curricular integration. In this sense, we were also able to explore approaches found in constructivist theories of learning, interdisciplinary teaching methodologies, and articulation with the integrating mediation of the students.

The innovative nature of this study showed that the convergence with the discipline of physical education facilitated the integration of knowledge and removed the historical neglect to which the discipline had been subjected with regard to its inclusion in professional education and other levels of education. Thus, we could see that the participation of students in collective activities went beyond the moments of interaction with their peers. There was the development of motor, cognitive, and social skills.

The physical activities favored inclusion of exercise adaptations in the Tabata practice in order to embrace a significant part of the subjects in the development of the class. It was an important factor in the closure of the ITS since it enabled the integration of knowledge and promoted debate among groups. As a result, it generated interaction between students and teachers, respect for the rules of dynamics, and appreciation of collective learning.

Changing the design of the traditional classroom by organising the chairs in a circle instead of a line promoted better interaction among the students. This disruptive teaching proposal contribute to the effective learning through participation in mediated activities. In the integration of different areas, the intention of the interdisciplinary teaching systematized in a teaching sequence proved to be an imperative apparatus of resistance and insurgent manifestation against fragmented teaching under a perspective of scientific and social integration of knowledge. It was an event characterized by the connection between theory and practice by highlighting the transversality of environmental education and interdisciplinarity.

In addition to STSE education, the interdisciplinary aspect of the stydy was not limited to the development of

multiple dimensions by which the content can be addressed and recognized as part of a construct of human relations. The sense of collectivity translated into a fertile environment for the construction or exchange of knowledge and experiences between students and teachers. Thus, we realized that the interdisciplinary perspective promoted a greater socialization of knowledge and that the integration of the collective was not reduced only to the last activity of the ITS with the Tabata circuit.

With the condition of connection between curricular disciplines, we went beyond the teaching content of learning between each other in an integrated high school, working as fundamental scientific elements for the identity formation of subjects who can see themselves as part of a collective community that shares habits, values, customs, and worldviews. Therefore, we consider that the school should not focus only on the process of performance and individual merit of students, but also consider them as a part of a school community that has ambitions and desires. Students should participate in the political and social life and build their way to the world beyond their differences.

We explored not only the interdisciplinarity as a teaching strategy but also the articulation among environmental, scientific, and collective learning and the promotion of outdoor physical activities. Students' understanding of the relationship between collectivity, physical and mental health, quality of life, and school performance revealed the importance of approaches that go beyond the formal curriculum content aiming at a more comprehensive and contextualized training. The critical analysis of these results effectively contributes to the reflection on innovative pedagogical practices and their impacts on the academic and social development of students.

The teaching sequence with an interdisciplinary view and STSE approach can be considered as an important methodological possibility for the systematization of school content and the providence of integrated teaching in professional and technological education. This contributes to the observation of the attributes discussed in this study, and others, which may also favor the integral and omnilateral formation of the student.

## 6. Limitations

The study provides valuable insights about the benefits of interdisciplinary education for improving scientific and environmental literacy. The small number of students from a single high school who participated in the present educational module limits the applicability of the findings to other courses. Future studies conducted in various academic environments with diverse groups of students could enhance and expand these findings, potentially improving their universality. Additionally, use of other instruments such as interviews and focus groups can increase the efficacy of this study. The possibility to have a long-term evaluation of the students such as a semester term can improve the quality of the assessment.

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## Authors' contributions

All authors contributed equally to the study.

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## Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Informed consent

Obtained.

## Ethics approval

The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

## Provenance and peer review

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## Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

**Data sharing statement**

No additional data are available.

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