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The Energy Theme as a Facilitator of Transdisciplinarity

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ABSTRACT

Background: Topics covered in chemistry classes are classified as decontextualized and not related to other knowledge, or to people's daily lives**.** **Objective:** to present a suggestion of simple, inexpensive experiments for science and/or chemistry classes and, from them, demonstrate how to associate chemistry with other areas of knowledge. **Design:** Detection of the presence of starch in coleus leaves after being kept in different conditions of light, water and CO_2 supply during their development. Ethanol production from the alcoholic fermentation of simple carbohydrates. **Participants:** A total of 29 published scientific works were used: scientific articles, conference communications, book chapters, and official documents from the Brazilian federal government and the state government of Rio Grande do Sul, as well as from international organizations. **Data collection and analysis:** National Common Curriculum Base (BNCC), Gaúcho Curriculum Reference (RCG) and Scientific articles that describes the experiments as well as analyze possibilities of transdisciplinary activities in the elementary and high school. **Results:** Starting from very simple experiments, detection of starch in leaves of plants, subjected to different conditions, such as suppression of the supply of air and sunlight and, production of alcohol from alcoholic fermentation, it is possible not only to work with several of the chemical concepts but also create a link with subjects from other curricular components according to the BNCC and RCG, facilitating interdisciplinarity and transdisciplinarity. **Conclusions:** In this context, teachers are no longer transmitters of knowledge, acting as mediators in the teaching-learning process, and students have a more active role in the acquisition of knowledge, being protagonists in the construction of their knowledge.

Keywords: chemistry, practical classes, protagonism

O tema energia como um eixo facilitador da transdisciplinaridade.

RESUMO

Contexto: Temas abordados nas aulas de química são classificados como descontextualizados e não relacionados a outros saberes, nem tão pouco ao cotidiano

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das pessoas. **Objetivo**: apresentar sugestão de experimentos simples, não onerosos, para aulas de ciências e/ou química e, a partir deles demonstrar como associar química com outras áreas do conhecimento. **Design**: Detecção da presença de amido em folhas de coleus após terem sido mantidas em condições diversas de fornecimento de luz, água e CO_2, durante seu desenvolvimento. Produção de etanol a partir da fermentação alcoólica de carboidratos simples. **Participantes:** Foram utilizadas, o total de 29 trabalhos científicos publicados: artigos científicos, comunicações em congresso, capítulos de livros, documentos oficiais do governo federal brasileiro e governo do estado do Rio Grande do Sul, bem como de organizações internacionais. **Coleta e análise de dados**: Base Nacional Curricular Comum, Referencial Curricular Gaúcho e Artigos científicos que descrevem os experimentos assim como analisam possibilidades de atividades de transdisciplinaridade nos ensinos fundamental e médio. **Resultados**: Partindo de experimentos muito simples, detecção de amido em folhas de plantas, submetidas à diferentes condições, como supressão do fornecimento de ar e luz solar e, produção de álcool a partir de fermentação alcoólica, é possível não somente trabalhar vários dos conceitos químicos, como criar um elo com assuntos de outros componentes curriculares segundo a BNCC e o RCG, facilitando a interdisciplinaridade e transdisciplinaridade. **Conclusões**: Neste contexto professores deixam de ser transmissores de conhecimento, atuando como mediadores no processo ensino-aprendizagem e, ou estudantes passam a ter um papel mais ativo na aquisição de conhecimento, sendo protagonistas na construção de seus saberes.

Palavras chaves: química, experimentação, protagonismo

INTRODUCTION

We live in an increasingly connected world, with unrestricted access to knowledge and technologies, but even so, the concatenations between available knowledge are reduced. In 2005, the United Nations Educational, Scientific and Cultural Organisation (UNESCO) published the report Education for All (EFA Global Monitoring Report), which they believe is extremely important to ensure that children, youth, and adults have access to knowledge and develop the skills necessary for their role in building society and improving their lives' conditions (UNESCO, 2004). The report defines the Four Pillars of Education for the 21st Century: Learning to Know, Learning to Do, Learning to Live, and Learning to Be.

The first pillar, Learning to Know, deals with the need to awaken the students with interest in discoveries. Given the amount of knowledge produced, it is impossible to know everything, but knowing how to access this knowledge when necessary and the tools used for it is essential and should be part of one's life (Rodrigues, 2021). Learning to Do, the second pillar, is related to the use of learned knowledge, and it is not enough to do it, but how to do it in a creative and innovative way, which, in turn, leads to cooperative work. The development of these skills is directly related to the third pillar, Learning to Coexist. This pillar assumes that it is essential to learn to live together. Living together means respect, empathy, and not excluding one or the other due to their different abilities. Engaging in social projects of interest to one's community demonstrates a new way of acting with oneself, others, and society (Rodrigues, 2021). Learning to be, the fourth pillar, provides for the citizens to be always up to date, to seek quality in their daily lives, and this will only be possible if they have a comprehensive education, with skills development, access to knowledge, culture, and health (Rodrigues, 2021).

Inadvertently, knowledge is fragmented, as if there was no possibility of uniting and/or using these fragments to explain the same phenomenon. An integrated curriculum helps students understand their context better, and teachers who use integrative methodologies notice that learning (Hardy et al., 2021). Students who participate in integrated and/or interdisciplinary curricula demonstrate better performance in the Programme for International Student Assessment (PISA) than students who get conventional teaching (Drake & Savage 2016). The application of an integrated curriculum often includes project-based learning, which naturally steers learning towards a more interdisciplinary model (Hardy et al., 2021). An integrated approach to teaching contributes to improving student/student interaction. Their learning and comprehension are enhanced, the application of acquired knowledge becomes more effective, and reading, writing, and math skills are developed, making these students more prepared to interpret and, in turn, interact more consciously with others, exercising their citizenship (Hardy et al., 2021).

Some recent proposals try to establish connections and cooperation between knowledge, which can be interdisciplinary, multidisciplinary, multidisciplinary, or transdisciplinary. However, despite being frequently found in the scientific literature, these concepts still need to be better defined. According to Hardy et al. (2021), a monodisciplinary approach is related to a single discipline. The multidisciplinary approach engages professors from different disciplines. They work together, but each in their area of knowledge. The interdisciplinary method integrates knowledge from several disciplines, and transdisciplinary goes beyond, overcoming the divisions between the different areas of knowledge (Hardy et al., 2021).

The term transdisciplinarity was first mentioned in the 1970s by Piaget in the I International Seminar on Pluridisciplinarity and Interdisciplinarity, held at the University of Nice in France (Bicalho & Oliveira 2011). Like the other proposals, transdisciplinarity aims to integrate disciplines and knowledge, bringing a specific knowledge closer to another specific knowledge. In 1986, UNESCO prepared the Venice Declaration, which postulates that only the exchange between sciences and different empirical knowledge could open the door to a new vision of humanity; besides, it says that the need for authentically transdisciplinary research that presents exchange initiatives between natural and social sciences, art, and tradition, can lead humankind closer to reality, which would allow us to more accurately face the challenges imposed today.

In the 1990s, transdisciplinarity resurfaced as something capable of helping to solve complex global problems, such as sustainability and climate change, and related to science, technology, politics, education, and social problems (Bernstein 2015).

The process of transdisciplinarity involves a series of principles, according to Scholz (2020), and educational institutions must ensure that all those involved have their roles, but also are independent, thus ensuring the joint development of solutions. They must be able to evaluate the knowledge obtained from science and practice, accepting the differences related to each of these types of knowledge. Another point to highlight is that mutual learning must be a basic principle, and transdisciplinarity must be able to initiate, integrate, and relate a discourse that involves the various areas of knowledge (Scholz, 2020).

An education based on sustainability can make one perceive the complexity of environmental, social, economic and political relationships, and the only one capable of facilitating this understanding and interaction between cultures, institutions, and different knowledge is transdisciplinary (Padurean & Cheveresan, 2010). Sustainable development has a major challenge: how scientific knowledge will be able to interact with other forms of knowledge, such as empirical knowledge obtained from sustainable experiences and/or practices (Scholz, 2020).

To think about transdisciplinary teaching is to defend the integration of knowledge and specific thoughts from each area of knowledge, as each has its own tools and methods for investigation. What interdisciplinarity actually intends is, using these specific languages/tools of different types of knowledge, to open up new opportunities/possibilities to interpret a given phenomenon, integrating knowledge in a more significant way (Burnard et al., 2021). But, in what way could the change in paradigms, in knowledge integration, where a field of knowledge advances towards another field's territory, contribute to learning?

According to Brazilian legislation, basic education comprises elementary and secondary education. The Law of Directives and Bases-LDB (BRASIL, 1996) guarantees all students the right to learning and development. The National Common Curriculum Base (BNCC) defines essential learning throughout all basic education stages. They define the general competencies required to mobilise knowledge, skills, attitudes, and values that enable the students to solve everyday life problems and fully exercise their citizenship (BNCC, 2018). In this way, teaching stimulates actions that are relevant in transforming society, making it fairer and concerned with preserving nature and life, corroborating with the provisions of Agenda 30 of the United Nations Organisation (UN, 2018). In basic education, students must take ownership of both knowledge and the ability to apply them in their daily lives.

In the final years of elementary school, students must be encouraged to explore experiences, knowledge, interests, and curiosities about the natural and material world, in addition to becoming aware of the organisation of different knowledge related to the various areas of knowledge. In high school, it is essential that the school welcomes young people and is committed to the integral formation and construction of the students' life projects (BNCC, 2018).

At the end of elementary school, students should be able to make relationships between science, nature, technologies, and society and understand environmental/natural phenomena using scientific and technological knowledge. Moreover, throughout high school, by articulating biology, physics, and chemistry in the natural sciences and its technologies, they must develop skills and abilities that allow expanding and systematising the learning accessed throughout elementary school (BNCC, 2018).

The state of Rio Grande do Sul created the Gaúcho Curriculum Reference for High School – RCG (SEDUC, 2021), which presents what is expected from teachers and students and gives theoretical support and procedures that should be adopted in the education of adolescents, young people, and adults. In general terms, the RCG proposes high schools have "[...] a perspective of emancipatory education, as it encourages teachers and students to transform the classroom environment according to their personal choices or options, in line with their own needs more genuine desires and yearnings and to their life project, in social interaction and aware of their condition as actors and actresses, protagonists, in individual and social edification (page 20, 2021)". The document also suggests that teaching practices make use of transversal and transdisciplinary practices, as they "[...] allow access to students' previous experiences outside the school environment and suggest that they be understood according to new levels of abstraction related to several areas of scientific study, contributing to the expansion of autonomy (page 21, 2021)”. Environmental education and conscious consumption are part of contemporary transversal themes; thus, these themes are not the domain of a specific area of knowledge but can be used to connect the various knowledges.

Taught in high school, chemistry is part of the natural sciences and its technologies. It aims to contribute to the education of students, expanding their competencies and abilities, developing their autonomy in the exercise of citizenship and contributing to the development of their understanding of society (Lima Júnior, Campos, & Rocha, 2014).

Most students at different levels of education say they do not like chemistry classes and even categorise the contents covered as difficult to understand and, not infrequently, say they do not see a relationship between the content and their daily lives. However, despite all this, and even though most people do not realise it, chemistry is present in our daily lives, from the water we drink, the air we breathe, the objects we use, the combination of ingredients in a recipe, the metabolism of fauna and flora. Apprehending this knowledge and applying it to understand the natural world, design, perform, and evaluate actions contributes to a more conscious and citizen education (Lima Júnior, Campos, & Rocha, 2014).

In high school, one of the competencies provided by the BNCC is “to analyse natural phenomena and technological processes, based on interactions and relationships between matter and energy, to propose individual and collective actions that improve production processes, minimise socio-environmental impacts and improve living conditions locally, regionally, and globally” (BNCC, 2018). Those competencies are developed in at least two skills: “analysing socio-environmental, political, and economic issues related to the current world’s dependence on non-renewable resources and discussing the need to introduce alternatives and new energy and material technologies, comparing different types of engines and production processes of new materials” - EM13CNT309, or “analysing and representing, with or without the use of specific digital devices and applications, the transformations and conservations in systems that involve quantity of matter, energy, and movement to make predictions about their behavior in everyday situations and in production processes that prioritise sustainable development, the conscious use of natural resources, and the preservation of life in all its forms” - EM13CNT10, throughout the three years of training (BNCC, 2018).

Thinking about learning in chemistry today is to think that the students bring to school a load of information that should not be neglected. Instead, it must be used as support in the classroom, so that their previous experience helps contextualise and enrich the classes, valuing their social and cultural environment, as recommended by the BNCC (2018): "It is important to highlight that learning natural sciences goes beyond learning its conceptual contents. From this perspective, the BNCC in the area of natural sciences and its technologies —through an articulated look at biology, physics, and chemistry— defines competencies and skills that allow the expansion and systematisation of essential learning developed in elementary school in what concerns: conceptual knowledge of the area; the social, cultural, environmental and historical contextualisation of this knowledge; research processes and practices and the languages of natural sciences" (BRASIL, 2018, p. 547).

Among the 17 Sustainable Development Goals, we have Goal 7, which aims to ensure reliable, sustainable, modern, and affordable access to energy for all. Moreover, it predicts that, by 2030, there will be a substantial increase in the share of renewable energy in the global energy mix and facilitate access to clean energy research and technologies, including renewable energy (ONU, 2018).

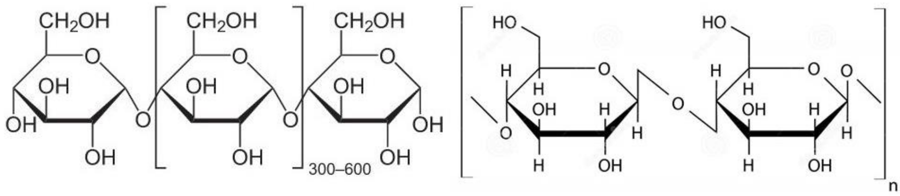
An important form of energy production is water and carbon dioxide converting solar energy into chemical energy through photosynthetic organisms, plants, and algae (Taiz & Zeiger 2013).

For living beings' metabolism to function well and survive, they must produce energy. Animals get energy from food intake and plants through the synthesis of molecules or biomolecules. The theme "Matter and Energy" is present as a thematic unit in elementary education throughout schooling, having, for example, as objects of knowledge of the 7^{th} grade: "sources and types of energy, energy transformation, being possible to work, from this object, the abilities to identify and classify different sources (renewable and non-renewable) and types of energy used in homes, communities, or cities" - EF08CI01 (BNCC, 2018).

In a very simplified way, the photosynthesis reaction can be represented by the following equation: $6H_2O + 6CO_2 + \text{luz} \rightarrow 6O_2 + C_6H_{12}O_6$, where water molecules, under the action of light, combined with carbon dioxide molecules, form glucose and oxygen, which will be used in their own respiration. On the other hand, plants store glucose molecules in the form of starch and cellulose (Figure 1).

Figure 1:

Structure of starch (a) and cellulose (b) molecules (Bioquímica, Campbell, 3rd ed.).



Starch and cellulose are the end products of photosynthesis and essential forms of carbon storage in plants due to their quantity and presence in the most diverse plant species (Martin & Smith 1995). Basically, starch is formed by a three-dimensional arrangement of glucose molecules, being accumulated in granules that can be found in leaves, seeds, and roots (Nawaz, Waheed, Nawaz & Shahwar, 2020). On the other hand, cellulose, a polymer formed by a long chain of glucose monomers (Taiz & Zeiger 2013), is found in all parts of a plant.

After its synthesis and storage, starch is then used by plants as a source of energy both for their metabolism, during dormancy periods and during the seed germination process. Animals, including humans, use it in their daily diet (Aller, Abete, Astrup, Martinez, Van Baak, 2011). Moreover, starch and cellulose can be used for the production of second-generation alcohol (2G alcohol), being an alternative, low-cost, and renewable source that can replace, in some cases, energy from non-renewable and expensive sources, as is the case with oil (Marques, Moreno, Ballesteros & Gírio, 2018; Ji, Jia, Kumar & Yoo, 2021).

Therefore, we ask: Is it possible to use the energy accumulated by plants in the form of starch and/or cellulose to produce alcohol? Is it possible to verify the accumulation of starch in photosynthetic plants?

One way to do this would be through several steps, involving freezing with liquid nitrogen, of parts of a plant, extraction of starch through boiling, centrifugation, enzymatic activity using hexokinase and glucose 6-phosphate-dehydrogenase, following through a spectrophotometer the conversion of NAD into NADH (Smith & Zeeman 2006). Second Domurath *et al*. (2012), it is possible to verify the spectral distribution emitted by plants when subjected to light from high-pressure sodium (HPS) and light emitting diode (LED) lamps. Both are very arduous processes and require specific equipment and expensive reagents.

However, we can use simple and less expensive materials in our classrooms. To this end, we suggest simple, inexpensive, and practical activities that can be used as a thematic axis, facilitating interdisciplinarity and transdisciplinarity, thus making chemistry classes more attractive to elementary and high school students.

MATERIAL AND METHODS

a) **Starch visualisation**: Based on a practice available in the Biblioteca Digital de Ciências [Digital Science Library] (https://www.bdc.ib.unicamp.br/bdc/index.php) suggested by Pereira et al., the following materials are used according to the steps proposed here:

- plants known as Coleus (*Plectranthus scutellarioides*) in pots with soil, - plastic hoods (with and without air inlet) to cover the plants,

- aluminium foil to cover the hood,

- water (H_2O),

- Bunsen burner or water heater,

- ethyl alcohol 96 º,

- lugol 1% (iodine solution, I_2 1% + potassium iodide, KI 2%).

1- Submit the plants to different environments: A) with light, with CO_2 available and water (in a transparent hood with air inlet); B) with light, with water but without CO_2 (in a transparent hood without air inlet); C) without light, with water and without CO_2 (in a dark hood and without air inlet); D) without water (in a transparent hood, with air inlet) (Figure 2). You can also create other environments according to the students' creativity.

2- Keep the plants in the established conditions for at least 48 hours (this time can be varied to three or even seven days).

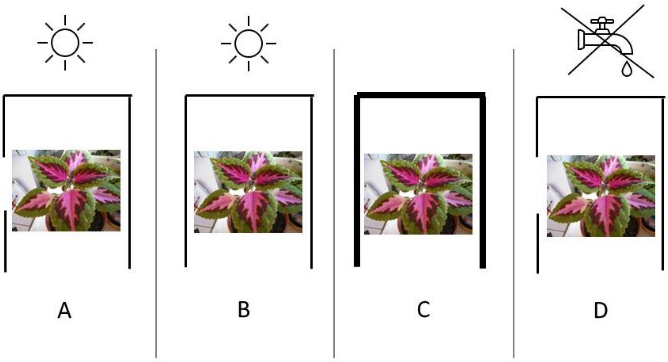
3. Remove one leaf from each plant. Dip each leaf for approximately one minute in boiling water, keeping it attached by a

string, taking care to identify the leaf - plant from which it was taken. After this time, transfer the leaves to ethyl alcohol until complete depigmentation.

4. Place the leaf dorsal side up in a Petri dish and treat with drops of Lugol. Make the correspondence between the location of starch accumulation and photosynthetic cells.

Figure 2:

Coleus plants kept in different conditions: A) light, CO_2 and water available (in a transparent hood with air inlet); B) light and water available, but no CO_2 (in a transparent hood without air inlet); C) water, without light and CO_2 (in a dark hood and without air inlet); D) without water, but with light and CO_2 (in a transparent hood, with air inlet).



B) **Ethanol production from sucrose**. Based on the experiment proposed by Gonçalves (2022):

- transparent glass or plastic bottles of approximately 200 mL;
- biological yeast;
- sugar;
- water;

Heat the water to about 40°C, and add the sugar and the yeast. Cap the bottle, follow the reaction and describe the observed changes.

RESULTS AND ANALYSIS

What can we expect after the execution of the experiment, as proposed? Lugol (based on iodine) can interact with polysaccharides, such as starch (Ferreira, Da Costa & Araujo, 2008), making the plant tissue in which this molecule is present darker. To visualise the colour change, one must remove all other molecules responsible for the pigmentation of the tested plant material. This is possible by boiling the leaf in water and then immersing it in alcohol. Starch is formed in the chloroplasts of photosynthetic cells and stored in amyloplasts in non-green organs (Taiz & Zeiger 2013).

Plants that received a period of sunlight, air, and water performed photosynthesis and produced more glucose for consumption; thus, the polysaccharides may be visible (Figure 2A). Plants that received a period of sunlight and water but not air also performed photosynthesis, producing glucose for their consumption, being, however, less efficient because they were deprived of CO_2. It is also possible that their polysaccharides can be seen (Figure 2B) but in a smaller proportion. Plants that only breathed consumed their caloric reserves to maintain their metabolism. In this way, glucose was not accumulated, and their polysaccharides cannot be visualised (Figure 2C). Plants that received a period of sunlight and air supply, but not water, also performed photosynthesis and produced glucose for consumption, and the polysaccharides are expected to be seen (Figure 2D). In this case, the synthesis of glucose and subsequent accumulation in starch can be reduced, as there is no water supply, which is essential for maintaining plant metabolism.

In the ethanol production experiment, the yeasts present in the biological yeast multiply and use sucrose as a source of energy. They convert the disaccharide into glucose through the enzyme invertase. Then, from the process of glycolysis and alcoholic fermentation, they produce ethanol, which can be detected through smell.

What about transdisciplinarity? Where is it? According to Bernstein (2015), transdisciplinarity requires changing teaching. Students can better organise their knowledge through cooperative, mutual projects of interest between the various curricular components. Teachers must use/search for ways to connect the various knowledges and scientific knowledge with everyday life. According to Iribarry (2003), transdisciplinarity does not intend to overlap the other subjects but to connect all of them with what permeates them.

Starting from this and using simple experiments such as visualising the accumulation of starch in plant leaves and producing ethanol from carbohydrates of vegetable origin, several themes/topics/subjects can be addressed. According to the BNCC, in the science curriculum component of the 9th grade of elementary school, we have as objects of knowledge, among others, the quantitative aspects of chemical transformations. Related to them, the following skills can be developed: “Compare quantities of reagents and products involved in chemical transformations, establishing the proportion between their masses” (EF09CI02); “Identify models that describe the structure of matter (atom constitution and composition of simple molecules) and recognise its historical evolution” (EF09CI03). So, in science/chemistry, the laws of conservation of masses and balancing chemical equations are some of the contents that this experiment can approach. To develop those skills, we must assume that students know how to identify, relate, and establish the proportions of the number of substances used and produced in chemical transformations based on their mass. It is paramount that teachers —the mediators in students’ knowledge acquisition— include experimental research activities in their teaching practice, including everyday chemical transformations, so students can learn to identify and represent simple and compound substances, use symbols, formulas, and equations that represent them, focusing on mass proportion and expanding their skills (EF09CI01). The recording and systematisation of information observed by the students should be valued, seeking direct and indirect evidence that helps construct explanatory models for the phenomena related to those transformations. The approach can be extended, due to the relevance of the theme, to the production system and the resolution of problems using reagents.

In the Portuguese Language, also in the 9th grade of elementary school, we can mention linguistic/semiotic analysis as one of the objects of knowledge, which brings as one of the skills the ability to write texts correctly, according to the official standards, with complex syntactic structures at the clause and period level (EF09LP04). This skill refers to the use of the standard norm in situations, genres, and texts. The production of texts reporting the experiments carried out, following the orthographic rules, according to the types of texts previously seen, can help interpret the result found in the practical activity. The possibility of giving lectures, seminars, oral presentations, participating in debates and interviews, and publishing a scientific dissemination article are also ways to develop skills and/or competencies.

In Geography, in the 9th grade, nature, environments and quality of life are part of the objects of knowledge and, with that, the possibility of identifying and analysing industrial and innovation chains and the consequences of the use of natural resources and different energy sources (EF09GE18). This skill concerns recognising, understanding, and critically evaluating the uses of natural resources from different energy sources (thermoelectric, hydroelectric, wind, and nuclear) in different countries to analyse the impacts and consequences of those uses on industrial production and innovation. The BNCC (2018) also highlights, in the Geography component, the relevance of promoting and including the organisation of content in the curriculum in such a way that it is possible to understand the environmental issue in conjunction with production chains and available natural resources.

Probability and statistics are objects of knowledge in the Mathematics curricular component in the 9th grade of elementary school. The planning, execution of sample research and report presentation can be developed with the ability to plan and execute sample research involving the theme of social reality and to communicate the results through a report containing an evaluation of measures of central tendency and amplitude, tables and appropriate graphs, built with the support of electronic spreadsheets (EF09MA23).

Experimentation is also part of the Charter of Transdisciplinarity. Article 11 provides that: “An authentic education cannot privilege abstraction in knowledge. It must teach to contextualise, concretise, and globalise”.

Stimulating those transdisciplinary activities based on simple experiments in class and uniting several areas of knowledge —science, mathematics, geography, history and portuguese language— cannot only improve knowledge apprehension but also have a positive impact on the lives of students and their community (Burnard et al., 2021), as students come to realise the interconnection of knowledge and their importance in everyday life.

In high school, this same practical activity can be performed and opens up possibilities to be used in various curricular components. One of the competencies, Natural Sciences, establishes that students should be able to analyse natural phenomena and technological processes, based on interactions and relationships between matter and energy, to propose individual and collective actions that improve production processes, minimise socio-environmental impacts and improve living conditions at the local, regional, and global levels. For example, the production of second-generation alcohol from plant material, which is usually discarded inappropriately, can be an alternative for obtaining energy that does not generate a severe environmental impact, besides contributing to the development of the community where the school is. With this, skills such as discussing the importance of preserving and conserving biodiversity, considering qualitative and quantitative parameters, evaluating the effects of human activity and environmental policies to guarantee the sustainability of the planet (EM13CNT206), or analysing socio-environmental, political issues and related to the current world's dependence on non-renewable resources, and discussing the need to introduce alternatives and new energy and material technologies, comparing different types of engines and production processes of new materials (EM13CNT309) can be developed. With this, students should have the ability to propose or participate in actions to investigate challenges of the contemporary world and make ethical and socially responsible decisions based on the analysis of social problems, such as those related to health situations, sustainability, the implications of technology in the world of work, among others, mobilising and articulating concepts, procedures and languages specific to mathematics, which is part of the skills to be developed by mathematics in high school (BNCC, 2018).

According to the RCG, some of the skills that 3rd-grade high-school students should develop are related to the risks involved in the indiscriminate use of natural resources. Students should also be able to discuss dependence on fossil fuels, their environmental impact, and offer alternatives for producing clean energy to protect the environment. Thus, they use the scientific knowledge they learned to propose solutions to local/regional and even global demands (RCG, 2021).

In Applied Human and Social Sciences, one of the general competencies, according to the BNCC, is: exercising intellectual curiosity and using the scientific approach, including research, reflection, critical analysis, imagination and creativity, to investigate causes, develop and test hypotheses, formulate and solve problems and create solutions (including technological ones) based on knowledge of different areas. From there, one of the skills to be developed is "to identify, analyse and discuss the historical, geographical, political, economic, social, environmental, and cultural circumstances of conceptual matrices (ethnocentrism, racism, evolution, modernity, and cooperativism/development, among others), critically evaluating their historical meaning and comparing them to narratives that contemplate other agents and discourses" (EM13CHS102), throughout the three years of high school. Once again, the production of second-generation alcohol from starch or cellulose can be addressed in this curriculum component.

Regarding the transversal themes proposed in the Gaucho Curriculum Reference for chemistry, the document states that ethics in consumption should be addressed in the third grade (RCG, 2021). Article 13 of the Charter of Transdisciplinarity provides that: "Transdisciplinary ethics refuses any attitude that denies dialogue and discussion, whatever its origin, whether ideological, scientific, religious, economic, political, philosophical. Shared knowledge must lead to a shared understanding, based on absolute respect for otherness united by common life on one and the same Earth". It is even clearer the importance of "knowing environmental rights, animal rights and cultures that promote the quality of all living beings, such as the philosophy of good living" as provided for in the RCG. Added to this, "knowing and analyzing the Universal Declaration on Bioethics and Human Rights: human dignity; right to life and research", recognizing the fundamental role, not only of chemical, physical, and biological knowledge but of all knowledge, in current technological development (RCG, 2021).

In this context, transdisciplinarity suggests that science be done with society and not just for society so that it can appropriate sustainable innovations, one of the premises of the sustainable development objectives provided by the UNO (Scholz, 2020).

Throughout the transdisciplinary teaching process, one must start with a project (project-based learning is part of the transdisciplinary method) that meets the interests of society/school community and, only through the interaction between these two will it be possible to meet solutions to a problem, promoting actions aimed at future sustainable actions (Scholz, 2020).

As one of the competencies to be developed throughout basic education, the BNCC states: "Value the diversity of knowledge and cultural experiences and appropriating knowledge and experiences that allow them to understand the relations of the world of work and make choices in line with the exercise of citizenship and their life project, with freedom, autonomy, critical awareness, and responsibility" (BNCC, 2018). Also according to Scholz (2020), science needs to change its objective and seek to interact more with society than just for society. One of the main obstacles to sustainable development must be the interaction of scientific knowledge with other knowledge, such as existential and empirical knowledge and experiences accumulated and passed from generation to generation (Scholz, 2020). Transdisciplinarity, as it is currently presented, suggests that science be done with society so that together they can develop sustainable solutions and innovations, actions that are globally recognised (Scholz, 2020).

CONCLUSIONS

Permeating pedagogical practice with classroom experiments facilitates understanding natural phenomena, how some factors affect our lives

(Souza, Rodrigues & Ramos, 2016), and how we can better use natural resources. However, for constant practice and the experience to be meaningful, teachers must be prepared to also respond adequately to the questions arising from the analysis of the results, contributing to the student's understanding.

During classroom experimentation, the teacher plays the role of an advisor, stimulator, instigator, and mediator (Souza, Rodrigues & Ramos, 2016) while the students assume the role of protagonists of their learning.

Encouraging experimentation in the classroom corroborates the provisions of the National Common Curriculum Base (BRASIL, 2018) which considers science an area of knowledge that allows students to, throughout their training, better explore their relationships with themselves, with others, with nature, with technologies and with the environment, developing ethical and political values, thus becoming responsible, conscious, supportive, and cooperative citizens. "The investigative approach should promote students' central role in learning and applying processes, practices, and procedures from which scientific and technological knowledge is produced. At this stage of schooling, it must be triggered from open and contextualised challenges and problems to stimulate curiosity and creativity in the elaboration of procedures and in the search for solutions of a theoretical and/or experimental nature [...] It is worth noting that, more important than acquiring the information itself, it is learning how to obtain it, produce it and critically analyse it" (BRASIL, 2017, p. 551).

Classroom experimentation contributes to interdisciplinarity and transdisciplinarity, which are so necessary for students to develop skills for questioning, exploring, developing hypotheses, analysing, and argumenting (Silva, Moura & Nogara, 2020). In this context, monitoring the experiment proposed in this manuscript, photosynthesis, the subsequent synthesis of starch by plants and its use to produce second-generation alcohol, a renewable source of energy, can greatly contribute to establishing connections with everyday life and is a link between the most varied forms of knowledge.

Teaching with a transdisciplinary approach requires meticulous lesson planning, as teachers must establish solid connections between scientific knowledge and everyday knowledge of society (Santos et al., 2018). At the same time, students need to realise they are actors in this process; they should be engaged to perceive connections between what they learn and what surrounds them, giving greater importance to scientific knowledge (Santos et al., 2018).

Transdisciplinarity is seen as a practice that intends to transcend and transgress the boundaries of the subjects and also seems to have great potential to meet the demands imposed by society. And this ability is directly related to the characteristics of transdisciplinarity: focus on the problem, the research starts with real problems; the methodology involves processes that can answer specific questions; encourages the participation of all: students, teachers from the most diverse areas, and people from the community with empirical experience obtained from their experiences (Burnard et al., 2021).

Chemistry can link the various scientific and empirical knowledge fields, helping students develop desired skills and act as citizens aware of their roles in society (Hardy et al., 2021). Chemistry is, therefore, a necessary curriculum content because, integrated with other areas of knowledge, it can be essential in transdisciplinary solutions in a highly complex real world and, with this, help with the problems encountered to achieve the sustainable development objectives proposed by the United Nations (Hardy et al., 2021).

Transdisciplinarity is complex but, at the same time, separates and unites, configuring emergencies without reducing them to basic, simple units. Its principles are based on different areas of science, such as biology, physics, and chemistry, among others (Martinazzo, 2020).

The definition of transdisciplinary is not a consensus. It has been discussed since the late 1970s (Colóquio de Córdoba, 1979) and early 1980s (Declaration of Venice, 1986) and, in 1992, a group was created at UNESCO to discuss the topic. In 1994, thinkers on the subject drafted the Charter of Transdisciplinarity.

Article 3 of the Charter of Transdisciplinarity states that: “Transdisciplinarity does not seek mastery of several disciplines, but the opening of all disciplines to what unites and surpasses them”. According to this article, it is necessary to find points where knowledge converges, but not only. It is necessary to go further, to provide opportunities for students to develop attitudes, and skills for their ethical performance in society, for example, corroborated by what is set out in Article 4: “... it presupposes an open rationality, through a new look at the relativity of the notions of definition and objectivity”.

The school (and the university) must, among other functions, help us find solutions to global problems, such as poverty eradication, health, hunger, water potability, and clean energy (included in the UN Sustainable Development Goals). This function meets what is foreseen in Article 11 of the

Charter of Transdisciplinarity: "... contextualise, materialise, and globalise. Transdisciplinary education reassesses the role of intuition, imagination, sensitivity and the body in the transmission of knowledge".

Without proper contextualisation, school knowledge becomes irrelevant to students, as they are transmitted in a fragmented way; thus, one cannot perceive the interactions between the various parts of knowledge and their relationship with the whole. Therefore, the school must rethink its performance, its way of thinking so widespread in the current teaching and learning model, and realise the need to problematise reality (Martinazzo, 2020).

The current disciplinary teaching model has proved inefficient in understanding and solving social problems. The transdisciplinary model allows for integration between knowledge, and the process as a whole respects students' knowledge. However, this new model makes teachers reflect on their teaching practices and realise that they, too, had few transdisciplinary examples in their education (Silva & Souza, 2018).

The growing advance of knowledge and the development of technologies for the dissemination and sharing of this knowledge, such as Digital Information and Communication Technologies (TDICs) are, on the one hand, benefits. However, on the other, such progress increasingly impoverishes (and not just in the monetary sense of the term) those who cannot access the technology, boosting social and environmental inequalities.

It is urgent that degree courses, not only in chemistry but also in other areas of knowledge, use this transdisciplinary model throughout the education of new teachers as an alternative to knowledge fragmentation so present in science (Silva & Souza, 2018).

DATA SHARING POLICIES

Data sharing is not applicable to this article as this is publicly available bibliography research.

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