Comments on the teaching of thermodynamics in an environmental sciences post graduation discipline

Comentários sobre o ensino da termodinâmica em um ambiente ciências pós-graduação disciplina

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ABSTRACT
The sciences related to mathematics and that have mathematics as a tool present the same kind of problem in the learning process, hence, also, in their teaching; for example, the
teaching of biophysics that show problems because is an exact discipline and, also, teaching for biological areas where people, usually, don’t is familiarized with mathematics way. In this work some didactic approaches to associate the teaching of thermodynamics to Environmental Science subjects in a literature search were performed, using the concepts of new teaching methodologies, proposing an approach to improve the conditions of understanding about environmental problems. A bibliographic survey was carried out by searching for data on thermodynamics, teaching, environmental sciences within the CAPES periodicals platform, which allows finding texts in other databases such as Scielo, Scopus, Web of Science. Additional material was obtained by searching in Google Academic. The main works consulted dealt more specifically with “exact sciences education”, “environmental education”, “biophysics education”, “environmental” and others. In total, 42 texts were analyzed and separated by subject content 21 about exact sciences education, 8 about environment education, 5 about biophysics education, 5 about environment and 3 for other subjects used to justify some ideas. Final considerations: In conclusion, the deficits in the teaching of exact sciences with a focus on thermodynamics are real in teaching in Brazil, with practical evidence in the discipline on Environmental Sciences in a graduate course, but whose students’ distress in learning mobilized a path of studies in the production of a work to alert and indicate ways, within the modern technologies of teaching, to assist the teaching of thermodynamics in education since elementary school. So, it is urgent that the teaching of environmental sciences is improved, that modern teaching technologies are made effective in teaching with an emphasis on the exact sciences, so that a more robust education allows important themes to be deepened in higher and post-graduate education with at least less discomfort for students and teachers.

**Keywords:** biomathematics, education, thermodynamics, environmental sciences, exact sciences education.

**RESUMO**

As ciências relacionadas à matemática e que têm a matemática como uma ferramenta apresentam o mesmo tipo de problema no processo de aprendizagem, portanto, também, em seu ensino; por exemplo, o ensino de biofísica que apresenta problemas porque é uma disciplina exata e, também, o ensino para áreas biológicas onde as pessoas, geralmente, não estão familiarizadas com a forma matemática. Neste trabalho foram realizadas algumas abordagens didáticas para associar o ensino de termodinâmica a sujeitos de Ciências Ambientais em uma busca de literatura, utilizando os conceitos de novas metodologias de ensino, propondo uma abordagem para melhorar as condições de compreensão sobre problemas ambientais. Levantamento bibliográfico foi realizado buscando dados de termodinâmica, ensino, ciências ambientais dentro da plataforma de periódicos da CAPES, o que permite encontrar textos em outras bases de dados como Scielo, Scopus, Web of Science. Material adicional foi obtido por meio de busca no Google Academic. Os principais trabalhos consultados trataram mais especificamente de "educação em ciências exatas", "educação ambiental", "educação em biofísica", "ambiental" e outros. No total, 42 textos foram analisados e separados por conteúdo temático 21 sobre educação em ciências exatas, 8 sobre educação ambiental, 5 sobre
educação biofísica, 5 sobre meio ambiente e 3 para outros assuntos usados para justificar algumas ideias. Considerações finais: Em conclusão, os déficits no ensino de ciências exatas com foco na termodinâmica são reais no ensino no Brasil, com evidências práticas na disciplina de Ciências Ambientais em curso de pós-graduação, mas cujas angústias de alunos na aprendizagem mobilizaram um caminho de estudos na produção de uma obra para alertar e indicar maneiras, dentro das tecnologias modernas de ensino, para auxiliar o ensino de termodinâmica na educação desde o ensino fundamental. Por isso, é urgente que o ensino das ciências ambientais seja melhorado, que as modernas tecnologias de ensino sejam efetivadas no ensino com ênfase nas ciências exatas, de modo que uma educação mais robusta permita que temas importantes sejam aprofundados no ensino superior e pós-graduação com pelo menos desconforto para estudantes e professores.

Palavras-chave: biomatemática, educação, termodinâmica, ciências ambientais, educação em ciências exatas.

1 INTRODUCTION

The teaching/learning of exact sciences at all levels of education has been considered precarious around the world today (ALVES; AVERSI-FERREIRA, 2019; FREITAS-FERREIRA; AVERSI-FERREIRA, 2021; AVERSI-FERREIRA et al., 2021) since the middle ages, the time when methods to improve mathematics teaching were tested (D’AMBRÓSIO, 1998; BIEMBENGUT, 2014). However, since the Greeks, methods for teaching mathematics were directed at task-based problem solving, thesis, construction, demonstration, and conclusion (GROENWALD et al., 2004).

The sciences related to mathematics and that have mathematics as a tool present the same kind of problem in the learning process, hence, also, in their teaching; for example, the teaching of engineering has failed worldwide to produce students prepared for the labor market (Borrego & Bernhard, 2011). However, by analogy, the problem of learning exact subjects is more complex for students in the non-exact sciences who require subjects based on mathematics and physics (AVERSI-FERREIRA et al., 2021).

An important example is the case in learning thermodynamics by undergraduate students in Turkey (ÜLTAY; DURUKAN; ÜLTAY, 2021) and in Mexico, who cited not seeing future prospects in the application of statistics in Environmental Sciences, which demotivated the study of this subject (SÁNCHEZ et al., 2021), an aspect that indicates
that the problem is worldwide in the teaching/learning of exact sciences (ALVES; AVERSI-FERREIRA, 2019).

After the middle ages, the teaching of exact sciences was tied to a problem-solving proposal called the Theory of Mental Discipline, started in Germany by the psychologist Christian Wolff in 1740, which proposed the resolution of extensive lists of exercises (ONUCHI et al. 2014), a technique used to this day by teachers in exact areas that do not align with modern teaching methods. This problem solving methodology does not necessarily include a logical analysis of the proposed problems before solving them, it only advocates the repetitive use of algorithms, which is currently criticized by authors in the field of education for emphasizing the product and not the learning (FRIZZARINI; CARGNIN, 2015), considering that the human mind is not only an automatic mechanism that produces answers (GROENWALD et al., 2004).

In fact, learning sciences in general, and especially exact sciences, is associated with problem solving, something intrinsic to the human thinking as a natural learning process since the dawn of the civilization due to the need for survival of individuals (AVERSI-FERREIRA et al., 2021).

However, the epistemology of teaching/learning in exact sciences is more complex as it requires a foundation that involves the didactic processes that associate teachers and students, a reflection and questioning in learning (FREIRE, 2005; CARAÇA, 1989), a critical thinking (MENDES, 2009), a teaching environment, methodologies, an interdisciplinary content, a teaching time, a society (LURIA, 1979), inter alia, aspects considered today within the so-called new teaching methodologies (BERNARDINIS et al., 2015; FRIZZARINI; CARGNIN, 2015; FRIZZARINI; CARGNIN, 2016) that are cited in the National Curricular Parameters (CORTES JUNIOR, 2017).

Despite the various studies and efforts to implement the new teaching methodologies that prioritize the reasoning, the interaction of the student with the society and its environment using everyday and practical problems, the tutoring of the teacher sharing the responsibility of teaching/learning with the students; the traditional teaching still prevails in Brazilian schools (AVERSI-FERREIRA et al., 2021; RODRIGUES;
MAGALHAES, 2012; GROENWALD et al., 2004), putatively, because of the difficulty in changing ingrained behaviors of students and teachers (ALVES; AVERSI-FERREIRA, 2019; BACHELARD, 1996).

In this sense, a study done with graduate students in Environmental Sciences showed that most of them felt more comfortable studying using traditional methods with lecture classes and an exercise list resolution (AVERSI-FERREIRA et al., 2021); the view of these students seems to corroborate the resistance of teachers to use new technologies in teaching that were identified in phrases such as "it has always been done the same way", "why change?", "I tried, but it didn't work" observed in another study (FREITAS; DORNELLAS; BELHOT, 2006).

But the logic in the teaching process goes through the need for the student to learn by reasoning and not only use the resources of memory and repetition activities without a critical thinking (PIUBÉLI; GOBARA, 2004). Considering that problem solving is essential for the science learning, since the Greeks, considered the fathers of mathematics since they were the first in history to recognize the need for the demonstration of mathematical truths (NOGUEIRA, 2015), this concern about problem solving exists (GROENWALD et al., 2004), but the problem solving methods had as its main exponent, within the recent teaching vision, George Pólya who wrote his problem solving methodology in the book "The art of solving problems" (PÓLYA, 1945), whose methodology can be used for the teaching of several sciences, exact and non-exact.

An analysis of the subjects within the non-exact sciences should be considered as a basis for understanding the teaching failures of the exact subjects and, as far as possible, proposals should be made to minimize the existing problems. One such case occurs in the Environmental Sciences that have become the center of attention of scientists and society in general due to the need to preserve the planet's resources in order to preserve it for the next generations within the context of sustainability (MAGRI; BRITO; AVERSI-FERREIRA, 2022), ecological awareness (PANOV, 2013), decreased pollution, waste disposal (SANTOS et al., 2012), inter alia.

The study of Environmental Sciences is multidisciplinary and the proof of the various environmental phenomena goes through the exact sciences such as chemistry,
mathematics and physics that associate to explain one of the main aspects studied for the verification of the environmental balance that is global warming (OOSTHOEK; GILLS, 2005).

Within this scope, the concepts of thermodynamics are a basis for the demonstration of the changes in the temperature of the globe. The demonstration is essential, as citing problems of temperature changes on the planet without an accurate basis can lead to a misinterpretation of data in separating what is human cause from what is natural cause (MAIBACH MYUERS; LEISEROWITZ, 2014).

Thermodynamic concepts are intrinsic to the explanation of energy phenomena involving biogeochemical cycles studied in Environmental Sciences (VALLINO; ALGAR, 2016), also in the study of pollution and waste disposal problems in the environment.

Considering the teaching/learning problems involving the exact subjects, it is reasonable to conclude that the understanding of thermodynamics concepts in Environmental Sciences may be neglected due to a lack of adequate knowledge of the principles of thermodynamics, a fact observed in some texts on Environmental Sciences (SÁNCHEZ et al., 2021) that, even having thermodynamics as a subject, only develop it theoretically with shallow concepts and without a mathematical analysis (OOSTHOEK; GILLS, 2005; MAIBACH; MYUERS; LEISEROWITZ, 2014).

The above issues, seen together and specifying for the teaching of exact sciences and environmental sciences, concomitantly, show that learning difficulties are a consequence, because the problems in the teaching of one influence the learning of the other, i.e., a poor teaching of exact sciences will generate a precariousness in the learning of the bases for the understanding of thermodynamics associated with environmental processes.

Considering the importance of the dissemination, study, and understanding of the environmental aspects that involve the planet, and that there are flaws in the teaching/learning of thermodynamics in environmental sciences, the pedagogical problems related to mathematics and exact sciences must be addressed.
This study was born from the difficulty in teaching thermodynamics in an Environmental Sciences subject in a post-graduation course in Environmental Sciences. The students' interest in deepening themes about global warming ran into deficits in their knowledge of thermodynamics, generating discomfort and anguish in the class.

In a conversation between the teacher and the students, it was concluded that the lack of knowledge about thermodynamics was a problem to deepen the theme about global warming and pollution, mainly, but on the general knowledge of environmental changes occurring on the Planet, as the more detailed knowledge of concepts of enthalpy, entropy and free energy.

Therefore, in this work some didactic approaches to associate the teaching of thermodynamics to Environmental Science subjects in a literature search were performed, using the concepts of new teaching methodologies, proposing an approach to improve the conditions of understanding about environmental problems.

In this sense, some topics about the teaching/learning of exact sciences will be commented on, without the pretension of a specific deepening, but with a focus on the teaching of thermodynamics, with the intention of preparing students to enter the courses of the biological areas with bases in exact sciences for the understanding of environmental sciences, and, for the undergraduate students who choose to study Environmental Sciences.

2 METHODOLOGIES

A bibliographic survey was carried out by searching for data on thermodynamics, teaching, environmental sciences within the CAPES [Coordenação de Aperfeiçoamento de Pessoas de Nível Superior - Brazil] periodicals platform, which allows finding texts in other databases such as Scielo, Scopus, Web of Science. Additional material was obtained by searching in Google Academic. The main works consulted dealt more specifically with “exact sciences education”, “environmental education”, “biophysics education”, “environmental” and others (Figure 1).
3 RESULTS AND DISCUSSION

In total, 42 texts were analyzed and separated by subject content 21 about exact sciences education, 8 about environment education, 5 about biophysics education, 5 about environment and 3 for other subjects used to justify some ideas.

3.1 COMMENTS FROM THE LITERATURE ON TEACHING EXACT SCIENCES AND THERMODYNAMICS

The proposal of teaching thermodynamics within environmental sciences is inserted in an interdisciplinary perspective of a discipline of exact sciences in a discipline of biological sciences, and that does not dispense with the existence of environmental sciences in the curricula of high schools and colleges (FARIA et al., 2022a), at least, since the institutional adoption of environmental education in Brazil was indicated in 1973, reinforced with the creation of the Special Secretariat for the Environment and National Environmental Policy (law 6.938/1981), in the 1988 Constitution in the National Policy for Environmental Education (law 90.795) and, still, within the National Curriculum Guidelines for Environmental Education by the CNE/CP opinion (number 14/2012).

The mentioned curricular guidelines indicate that environmental education should be present from the basic to the higher education (BRAZIL, 2012).
Environmental education, despite the space, today occupied, in the secular and academic society, has not obtained the same position within the school curricula, including in higher education where it is not a mandatory subject in many courses in the area of biological sciences, but it should be, especially in teacher training courses, which requires a review of curricula, disciplines, and, more deeply, of teaching methodologies (BOTELHO; COUTO; MASI, 2014).

In this sense, it is necessary to mention the importance of the implementation of the subject of environmental sciences in elementary and high school, to at least direct the interdisciplinary or transversality studies with themes related to the environment and sustainability (CORTES JÚNIOR, 2017) for the inclusion of the fundamentals of thermodynamics within part of this content, considering the importance of interdisciplinary studies in the training of students uniting, for example, science and biology on one side and mathematics and physics on the other (LAVAQUI; BATISTA, 2007), allowing teamwork and, at the same time of autonomy, in the educational path of the learner (OSÓRIO; GARCIA; MARTINS, 2019).

Within its scope, environmental science is interdisciplinary for showing the relationships of nature that are derived from various areas of study, so it presents a characteristic of transversality, as cited above, allowing broad connections between areas, as the case of thermodynamic analyses (MARTINS et al., 2015).

Using interdisciplinary and transversal methods, one avoids reductionist and conservative contents within the scientific approach in general and in the subject of environmental sciences, specifically (VALDANHA NETO; KAWASAKI, 2015), for example, as study and teaching proposals, thermodynamics can be inserted within the energy processes of the human body within the physics subject (PUHL; MARCHI, 2019), or one can create a joint approach of mathematics and sustainability in the teaching of biology and exact subjects, such as the use of numerical data to associate the consumption and the environmental impact in numerical mathematical situations in everyday life (MACHADO; FRANÇA, 2016).
On the other hand, within biology or geology, the study of the origin of life and geological and human history can be used as proposals for the analysis of modern environmental problems in terms of economics (MILLER; TYLER, 2008)

Alternatives such as teaching classical mechanics with music, economics, statistics, probability, interrelating historical knowledge and authorities of physics (HIEBERT, 2000); relating computer programming, physics, mathematics and studies of heredity and DNA (deoxyribonucleic acid) with the evolution of species and the entropy of biological processes (LONGO, 2009) are teaching proposals in which interdisciplinarity, history, and relationships with everyday life in a teaching event that involves society and the environment are indicated to improve the teaching process (ALVES; AVERSI-FERREIRA, 2019).

The above proposals run into a complex problem and so far unsolved in practice, which is the inefficiency of the teaching/learning process of exact sciences in general and, from what can be inferred by analyses, of the teaching of exact sciences to students from areas other than exact sciences, in this case, biological sciences, which was observed for subjects that are mandatory for this area, such as statistics (SÁNCHEZ et al., 2021).

The lack of grounding in the exact sciences by students is vastly proven (AVERSI-FERREIRA et al., 2021; ALVES; AVERSI-FERREIRA, 2019), especially when this knowledge is required in subjects such as biophysics in which students have difficulty in dealing with biological problems that require a foundation of physics concepts in which the student does not understand the process (SILVA; DIAS; LUNA, 2020). Proposals for teaching physics and biophysics with a more qualitative focus have been made to minimize biophysics learning deficits (SILVA; DIAS; LUNA, 2020), however, in general, all the deepening in any subject of biological areas requires the use of graphs, comparisons by ratio and proportion, percentages, numerical comparisons (SILVA; PIRES, 2012), which makes the proposal of a qualitative approach insufficient for the formation of a competent professional in terms of scientific analysis of the reality.
3.2 COMMENTS ON TEACHING THERMODYNAMICS IN A POST-GRADUATE ENVIRONMENTAL SCIENCE COURSE

Considering the authors' experience in the Environmental Science subject, the problem was that the students did not understand the physical basis of the global warming and pollution process.

The basics of the first and second laws of thermodynamics were bald and the problems of energy cycling, as it can neither be created nor destroyed, impacted the discussions about how the planet would disperse the energy generated in the global temperature increase, as it dissipates energy from the atmosphere to the cold neighborhood of the universe.

Then, issues such as the accumulation of energy in the chemical bonds held by compounds like CO2 and methane entered the discussion, but the chemical background on these issues was also lacking.

In this sense, even though thermodynamics was the main basis for the discomfort in learning about environmental problems, other exact subjects emerged as deficient.

The issues discussed above, in the first topic of this section, direct teachers to the need to use new teaching technologies to teach the exact sciences, as it was and it is widely discussed in the literature on teaching this area (AVERSI-FERREIRA et al., 2021; ALVES; AVERSI-FERREIRA, 2019; NOGUEIRA, 2015), and, for the specific case of thermodynamics (MAZARO; DARROZ, 2018), using cross-cutting and multidisciplinary themes (VALDANHA NETO; KAWASAKI, 2015), relating biology, physics, and chemistry, to stimulate the learning of thermodynamics.

An association of biological, metabolic processes, for example, with an energy expenditure seems to be one of the interesting ways to stimulate the student to become interested in thermodynamics and for the applied exact sciences, at least in high school.

In higher education, biophysics and biochemistry should provide students with knowledge about environmental and biological/metabolic thermodynamics, respectively, but these disciplines face the chronic problem of receiving students with deficient exact science bases.
In the specific case of biophysics, the contents rarely deal with environmental thermodynamics, another problem that needs to be corrected and discussed, but elsewhere.

In the case of the subject that generated this study, the proposal taken together was to make a survey on the problems of teaching thermodynamics, reported by the students and write a paper to direct the teaching of thermodynamics to improve the learning of Environmental Sciences in order to generate an understanding as real as possible of the global processes on the environment, which meets the student to be the author of his knowledge and choose the path of his learning.

This situation has generated a search for information about the scientific basis of thermodynamics and how to teach this subject, since the future of graduate students in Brazil is directly linked to teaching and research.

This situation is in line with studies that have shown that the teaching of Environmental Sciences in Brazil is deficient and needs to be monitored and improved at all levels of education in the country (FARIA et al., 2022b).

4 CONCLUSIONS

In conclusion, the deficits in the teaching of exact sciences with a focus on thermodynamics are real in teaching in Brazil, with practical evidence in the discipline on Environmental Sciences in a graduate course, but whose students' distress in learning mobilized a path of studies in the production of a work to alert and indicate ways, within the modern technologies of teaching, to assist the teaching of thermodynamics in education since elementary school.

So, it is urgent that the teaching of environmental sciences is improved, that modern teaching technologies are made effective in teaching with an emphasis on the exact sciences, so that a more robust education allows important themes to be deepened in higher and post-graduate education with at least less discomfort for students and teachers.
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