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ARTIGO

INTRINSIC RELATIONS AMONG CHEMISTRY, PHYSICS AND MATHEMATICS IN THE BRAZILIAN HIGH SCHOOL: A THEORETICAL-METHODOLOGICAL APPROACH

RELAÇÕES INTRÍNSECAS ENTRE A QUÍMICA, FÍSICA E MATEMÁTICA NO ENSINO MÉDIO BRASILEIRO: UMA ABORDAGEM TEÓRICA-METODOLÓGICA

RELACIONES INTRÍNSECAS ENTRE QUÍMICA, FÍSICA Y MATEMÁTICAS EM LA ESCUELA SECUNDARIA BRASILEÑA: UN ENFOQUE TEÓRICO-METODOLÓGICO

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Abstract: This paper reports an investigation into the dialogical relation among significant learning experiences of Chemistry, Physics and Mathematics contents in an interdisciplinary context. It aimed at answering the following questions that are relevant to the field of Exact Sciences: why do students show little interest in these courses?; where is the problem?; did Chemistry and Physics abandon Mathematics when they started to focus more on qualitative and theoretical concepts than on quantitative ones?; and how can the three courses work together to make both teaching and learning processes easier?. This study presented an actual overview of the Brazilian High School by highlighting strengths and weaknesses from the perspective of Chemistry, Physics and Mathematics teaching. The Brazilian educational scenario showed again that the three courses are the ones that students enjoy the least. The research methodology had a qualitative focus since it had an interpretative and descriptive nature. Answers given to the questions may be found in the text intertwined with some worrisome reflections, which also include the triad teacher-student-educational system. Results showed that further studies are needed to find out the reasons for multiple difficulties found in the intrinsic relations among Chemistry, Physics and Mathematics. It is disappointing to know that no satisfactory practical solution has been proposed so far. Everything has been kept in the educational ideal described by research articles, chapters and motivational quotes.

Keywords: chemistry teaching; physics teaching; mathematics teaching; basic education.

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Resumo: O presente estudo trata de uma pesquisa que buscou investigar a relação dialógica entre as aprendizagens significativas de conteúdos de Matemática, Física e Química em um contexto interdisciplinar. Buscou-se responder indagações pertinentes ao campo das ciências exatas como: por que observamos o pouco interesse dos estudantes nessas disciplinas? Onde está o problema? A química e a física abandonaram a matématica ao aprofundarem mais em conceitos qualitativos e teóricos ao invés dos quantitativos? Como as três podem atuar juntas facilitando o processo ensino-aprendizagem? Um panorâma real do ensino médio brasileiro foi mostrado destacando os pontos positivos e negativos a partir do olhar crítico das áreas de ensino de química, física e matemática. As disciplinas de química, física e matemática continuam no pódio das matérias menos amadas pelos estudantes. A metodologia de pesquisa teve um enfoque preferencialmente qualitativo, de caráter interpretativo e descritivo. Respostas às indagações iniciais podem ser encontradas em meio a algumas reflexões preocupantes. Pesquisas futuras são necessárias para verificar os motivos das multiplas dificuldades encontradas nas relações intrínsecas entre matemática, química e física. Lamentável que nenhuma solução satisfatória prática foi proposta, tudo ainda continua em um ideal educacional descrito apenas em artigos científicos, capítulos de livros e frases motivacionais.

Palavras-chave: ensino de química; ensino de física; ensino de matemática; educação básica.

Resumen: El presente estudio aborda una investigación que buscó investigar la relación dialógica entre el aprendizaje significativo de contenidos de Matemáticas, Física y Química en un contexto interdisciplinario. Buscamos responder preguntas pertinentes al campo de las ciencias exactas, tales como: ¿por qué observamos poco interés entre los estudiantes por estas disciplinas? ¿Dónde está el problema? ¿La química y la física abandonaron las matemáticas al profundizar en conceptos cualitativos y teóricos en lugar de cuantitativos? ¿Cómo pueden los tres trabajar juntos para facilitar el proceso de enseñanza-aprendizaje? El escenario educativo brasileño volvió a demostrar que las materias de química, física y matemáticas permanecen en el podio de las materias menos queridas por los estudiantes. La metodología de la investigación tuvo un enfoque preferentemente cualitativo, de carácter interpretativo y descriptivo. A lo largo del texto, las respuestas a las preguntas iniciales se encuentran en medio de algunas reflexiones preocupantes. Se concluye que aún serán necesarias futuras investigaciones para verificar las razones de las múltiples dificultades encontradas en las relaciones intrínsecas entre matemáticas, química y física. Es lamentable que no se haya propuesto ninguna solución práctica satisfactoria, todo sigue siendo un ideal educativo descrito sólo en artículos científicos, capítulos de libros y frases motivadoras.

Palabras-clave: enseñanza de química; enseñanza de física; enseñanza de matemáticas; educación básica.

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1 Introduction

Even though adolescence is the phase in which students start High School, youngsters and adults who were not able to finish it at the expected age may do it at any time in their lives; thus, the most appropriate word is youth (MIRON; SCHARDOSIM, 2021). This group has diverse lifestyles, wishes and projects. Schools have always taken on youngsters' dreams and contributed to enable them to get access to scientific knowledge, multiliteracy, technology, culture and professional development (PAIVA, 2018). Even though several courses compose youngsters' curricula, this paper focused on Chemistry, Physics and Mathematics teaching and their intrinsic relations.

Chemistry is primarily the science of transformations of matter. Chemists are supposed to answer two questions. One is related to Analytical Chemistry. Considering a certain quantity of matter, the question is: what is its composition? The other is related to Synthetic Chemistry. The question is: how can I get certain material? Both questions constitute the operational basis of Chemistry and Alchemy (ALFONSO-GOLDFARB; FERRAZ, 2011).

It is now known that Alchemy was not a science and that esoterism embedded in its procedures prevented actual construction of knowledge associated with matter composition and properties. Chemistry was just established as a science itself when it adopted a common language that enabled transmission of information, concepts and experimental procedures (VARGAS, 2017). The issue of language in Chemistry teaching is essential to develop scientific concepts. Vitality of Chemistry as a science depends mainly on how chemical ideas are expressed, taught and used, i. e., to be scientifically literate means to know how to read and interpret language that is written in nature (AGUIAR; CUNHA; LORENZETTI, 2022).

Physics teaching aims at arousing students' interest in Natural Sciences and at developing observation, logical reasoning and problem-solving skills (BERNARDINO; SANTOS, 2023). When students understand basic principles of Physics, they are able to interpret natural phenomena, question the world that surrounds them and search for answers through experimentation and scientific methods. Teaching Physics is often a challenge for teachers. Some students may find it hard to abstract physical and mathematical concepts, a fact that may hinder comprehension and lead to lack of interest. Therefore, it is important to use a pedagogical approach to teach Physics to students in a comprehensive, interesting and significant way (BERNARDINO; SANTOS, 2023).

Mathematics represents a challenge to most students. This course must be fun and promote students' personal growth, rather than be an instrument of exclusion or a punishment

for failure (BORGES; OLIVEIRA; BORGES, 2021). Mathematics teaching should introduce contents to students in practical ways. Thus, it is essential to connect school and formal contents to social life. One may think of several situations that involve political, social, environmental and ethical issues and in which mathematical thinking is a useful instrument (BORGES; OLIVEIRA; BORGES, 2021). Therefore, Mathematics enables students to make sense of the world that surrounds them and to acknowledge that mathematical knowledge is an instrument to understand the world, rather than a mere set of rules. As a result, students may become agents of social change.

Regarding particularities and relations among the three areas of knowledge called Exact Sciences, this study aims at collecting important aspects of Chemistry, Physics and Mathematics teaching in the Brazilian High School. When they are intertwined, or not, the three courses bring up complex and sensitive questions that are answered throughout the text. The main questions are the following: why do students show little interest in these courses?; where is the problem?; did Chemistry and Physics abandon Mathematics when they started to focus more on qualitative and theoretical concepts than on quantitative ones?; and how can the three courses work together to make both teaching and learning processes easier?

2 Methodological procedures

This study has a descriptive nature since it aims at understanding the whole phenomenon in its complexity; therefore, a qualitative analysis is the best choice (BENEDETTI FILHO *et al*., 2020). A qualitative methodology is chosen after the problem is defined and objectives of the study are established. It should be highlighted that qualitative investigations employ a model in which reality is rooted in subjects' perceptions; thus, it originates contextual information to collect data for analysis. Objectives of this methodological proposal are to understand and find significance in subjects' verbal narratives and behavior, rather than in statistical surveys which are provided by quantitative studies (BENEDETTI FILHO *et al*., 2020).

This study is also based on a literature review of papers published by Brazilian journals. Several papers were selected with the use of the following descriptors: relation between Chemistry and Physics; students' difficulties in Exact Sciences; reasons for low achievement in Chemistry, Physics and Mathematics and their qualitative concepts; how to improve Exact Sciences teaching in High School; and how Mathematics influences Chemistry and Physics learning. It should be mentioned that no specific period was established to search for papers in

databases, which were Web of Science, Scopus, SciELO, Portal de Periódicos da Capes and Google Acadêmico.

Thus, this study was also based on principles and fundamentals of bibliographic research whose objective is to make researchers aware of all material that has already been published on the topic (SOUSA; OLIVEIRA; ALVES, 2021).

3 Relations among Chemistry, Physics and Mathematics: what is the current reality in the Brazilian High School?

Concerning Chemistry, Physics and Mathematics teaching in the Brazilian High School, it is clear that their teaching and learning processes are neither so efficient nor so suitable to teachers' and students' development. On one hand, Physics has often been characterized as a difficult course. On the other hand, Mathematics is seen as a complicated course. Chemistry is added to the group as an abstract course. Chemistry, Physics and Mathematics have been closely related since the remote essence of scientific knowledge; the relation of mutual influence has been fundamental to their development (REIS; SANTANA; LEMOS, 2022).

However, in High School, students do not perceive the relation since they just apply formulas in Physics and do not even understand the meaning of the application. Therefore, problematization may be an appropriate way to trigger situations in which students, together with their teacher, may explore and investigate mathematical problems derived from Physics by means of actual and fun experiences that they face in their routine, such as daily tasks, events and games. Such problems include equation solving of bodies in free fall and object launching, such as rockets and cannonballs (ANJOS; SAHELICES; MOREIRA, 2017). In these cases, teachers may ask students to explain every phase of their process in terms of concepts and mathematical contents related to them. Mathematics is perceived in the chemical subject called colligative properties when students need to interpret graphs and tables (SILVA; ALMEIDA, 2019).

Chemistry is a course that requires students to use mathematical knowledge and skills to understand it. Some studies have pointed out that Chemistry uses mathematical language to develop competencies and skills related to the establishment not only of logical-empirical, logical-formal and hypothetical-logical relations but also of proportional reasoning. It should be highlighted that merely memorized algorithms and rules do not develop such competencies and skills. An example is the application of mathematical reasoning to chemical equation balancing (FAULSTICH; NOGUEIRA; BECK, 2018).

The area of Mathematics pervades the Natural Sciences and students should be able to use mathematical strategies, concepts and procedures to interpret situations in different settings, such as everyday activities, facts of Natural and Human Sciences and socio-economic and technological issues disseminated by the media, to contribute to general education (SCHMITZ; RITTER; SILVA, 2022).

The largest problem faced by Chemistry, in relation to Mathematics and Physics, is mainly found in the second year in High School (the sophomore year) since concepts of the three courses must be used in Physical Chemistry. An example is the use of exponential functions in introductory concepts of Thermochemistry. Besides, students who have difficulties in Mathematics do not feel attracted to Chemistry, as a consequence. In some cases, concepts of Mathematics may be well internalized but students find it hard to relate mathematical skills to problems in Chemistry (SÁ; SOUZA, 2023).

Several freshmen panic when they need to learn molecular geometry in Chemistry. Construction of molecular models requires previous knowledge of geometric and trigonometric fundamentals that enable molecules and their forms in space to be better visualized. Bi- and tridimensional representations in Chemistry permeate linguistic complements provided by Chemistry and Mathematics theories (FARIAS *et al*., 2015).

In the area of research into Physics teaching, several researchers in Education have asked the following questions: where exactly does such difficulty in learning Physics come from?; does it come from one or more High School courses?; does it come from one or more Elementary School courses, such as Mathematics and Portuguese?; is any course responsible for the independent fact of teaching modalities?; and is Physics itself to be blamed, since it requires much abstraction and calculation?. In fact, Mathematics structures physical knowledge, but the fact that students do not understand Physics cannot only be attributed to Mathematics, i. e., if Mathematics is the language that enables individuals to organize their thoughts to understand the world, Science teaching must encourage this skill (BERNARDO, 2020).

4 Mathematics teaching

To know Mathematics is not merely mastering algorithms needed to solve problems. Mathematics goes beyond learning techniques to operate with symbols since it is related to certain possibilities of interpreting, synthetizing, signifying, conceiving and transcending what is immediately sensitive, thus, extrapolating and projecting perspectives (RESENDE;

MESQUITA, 2013). However, some students say that Mathematics is "rocket science" since they cannot understand its basic concepts.

Mathematics renders not only the privileged instrument of analysis to modern Science but also the logics of investigation and the model of representation of the structure of matter. Complexity of Mathematics is not just an empirical phenomenon (chance, possibility, disorder, complication, mix of phenomena) but also a conceptual and logical problem which confuses rigid limits and boundaries of concepts, such as "producer" and "product", "cause" and "effect" and "one" and "multiple". The Brazilian society has required educational institutions to work on aspects and conditions that go much beyond pedagogical practices in Mathematics developed throughout teaching and learning processes, mainly in Basic Education (HOLANDA; FREITAS; RODRIGUES, 2020).

To improve Mathematics teaching, scholars suggest a set of actions, decisions and processes, with a certain degree of intentionality and systematization, to modify attitudes, ideas, cultures, contents, models and pedagogical practices. In addition, in the renewal process, they also recommend the introduction of new projects and programs, curriculum material, teaching and learning strategies, didactic models and different ways of organizing and managing curricula, schools and class dynamics (ZANELLA; ROCHA, 2020).

This bibliographic review showed somehow that there are few studies of this issue – Mathematics teaching and learning – and that, to improve its proficiency in High School, class pedagogical practices must be reconsidered in and out of school. Therefore, schools must propose more dynamic and interactive lessons that account for students' social context and connect contents to their lives in complex, interdisciplinary, innovative and intercultural ways (ZANELLA; ROCHA, 2020).

Data on Mathematics teaching in Brazil are not encouraging since they reveal its deficiencies through results of students' evaluation by an examination called *Sistema de Avaliação da Educação Básica* (SAEB). The Ministry of Education has shown a worrisome issue, i. e., Mathematics teaching and learning processes in High School have been mechanical and repetitive; teachers act as knowledge owners and students are mere recipients (TEIXEIRA; PEREIRA; MOREIRA, 2022).

Much is said about the need to improve proficiency in Mathematics but schools have found it hard to develop teaching and learning processes effectively. Besides, actions of teaching systems have not been efficient enough to improve learning, mainly Mathematics learning in Basic Education. Thus, this context requires further investigation so that both

obstacles and successful pedagogical practices may be known and better proficiency may be reached in Mathematics in High School (PALHETA; LUCENA; TAVARES, 2021).

5 Physics teaching

In the light of current ideas, reflection upon Physics teaching and learning requires questioning whether students have the possibility of carrying out scientific practices and how they are implemented in class. A central element is the importance of investigation and argumentation in Science teaching since they are essential practices in this field of knowledge. In the scope of Physics, not only argumentative language but also mathematical language must be considered a fundamental means of communication to construct ideas and disseminate knowledge. This statement agrees with the idea that Physics has not "abandoned" Mathematics at all; they complement each other (CARVALHO; SASSERON, 2018).

Reality of current Physics lessons does not befit actual needs and transformations in teaching. Knowledge of Physics has still been treated as an encyclopedic one which is a mere mathematical apparatus that does not always lead to comprehension of physical phenomena and ends up forming an aversion to the course. Knowledge of Physics should not be taught as being absolute because the truth from years ago may not be true anymore these days. A sad fact is that Physics lessons have not been attractive enough to draw students' attention and lead to aggregation to enable improvement in knowledge of Physics (MORAES, 2009).

The thorough analysis of selected papers showed that most students think that Physics is a quite difficult course. Observation has shown that the difficulty centers on interpretation and calculations. Thus, Physics taught in lessons still focuses on mathematical aspects. It shows a major error, committed by some Physics teachers, which is clearly addressed by textbooks. As a result, students often confuse Physics with Mathematics and cannot understand which role Mathematics plays in Physics is. Students end up developing some dislike for Physics because they start High School with plenty of mathematical difficulties they could not cope with in Elementary School (MORAES, 2009).

Taking into consideration the need to improve Physics teaching and, consequently, increase students' interest, this study advocates the need for more practical teaching with the crucial use of experiments. According to students, another way of making Physics teaching more practical is to implement technological resources in lessons (SILVA; BRINATTI; ANDRADE, 2022).

This contextualization intends to arouse a critical analysis, rather than exhaust discussions on the issue. In the past, students used to attend six 50-min lessons per week while they attend two, or fewer, nowadays. Laboratory lessons are almost nonexistent. There are few Physics teachers in schools and most have to train students to get good grades in exams and get right answers, rather than teach Physics. Interdisciplinarity and transdisciplinarity get confused with non-disciplinarity and blur the identity of Physics. Curriculum contents are limited to Classic Mechanics and are addressed in a traditional way which is centered on the teacher, based on a narrative model, on Freire's banking model of education and on Skinner's behaviorism. This type of teaching results in strong indisposition that makes them say – metaphorically – that they "hate" Physics, instead of developing predisposition to learn it, as expected in the case of significant learning (MOREIRA, 2018).

Unfortunately, Physics teaching, in general, leads to negative integration of thoughts, feelings and actions which makes students dislike Physics and avoid it whenever possible since they just want to write on exams "what was taught in class" and get good grades. What a shame! Teachers, managers and researchers must be aware that Physics teaching needs to be modified and that Physics cannot be lost. This issue seems to have been destroyed by market-based and behavioral education that trains students to succeed in national and international exams. There are exceptions in some educational contexts in Brazil but teaching focused on evaluation and testing is common, even if it is disguised amid other activities (NESI *et al.,* 2021).

6 Chemistry teaching

A recent study shows that Chemistry teaching is still based on activities that require memorization of information; as a result, learning is limited and students do not get motivated to study. Several limitations are related to difficulties in concept abstraction and elaboration and perception of Science models. High School students usually exhibit low learning levels in Chemistry, which are perceived through both internal evaluation processes in schools and external ones applied by programs funded by the Ministry of Education (SILVA; FILHO; ALVES, 2020).

Research into Chemistry Education became a strategic area in the mid 1960's when there was a movement to renew Science teaching which got stronger in the following decades after North American projects of Science teaching were translated. It led to the advent of a group of researchers in Physics, Chemistry and Biology who were interested in participating in multidisciplinary studies of issues related to Science learning (SANTOS; PORTO, 2013).

High School students' low achievement in Chemistry is a worrisome result since there is no scientific and technological development when the Basic Education system is not solid. Therefor, teachers must have sensitivity to perceive students' needs and how they can meet them with the use of didactic and dynamic teaching that makes students feel good and cares for each one. When students have difficulties, decreasing their self-esteem with bad grades or treating them differently from the others who show more knowledge cannot solve anything. However, teachers often plan their lessons to students who show some learning and neglect those who have difficulties. Teachers think that, if some students understand the topic, there may be something wrong with the others, i. e., they may not be working hard enough. However, teachers' didactic process may not consider students' individuality (SANTOS *et al.*, 2013).

The world has changed much in the last decades and research into Chemistry teaching has been fundamental to face problems related to the topic and typical of times of fast and deep changes. In the Brazilian case, it is quite easy to diagnose the population's bad results of Science Education. It is not fair to attribute bad results to recent trends in Science teaching, mainly to those which result from studies carried out in the area. Such argument just diverts attention away from real problems of national Education, such as teachers' devaluation and their poor working conditions in schools. A curriculum reform just reaches its objectives if Education is seen as a priority, rather than an object of a state policy (ANDRADE; PORDEUS, 2022).

Even though there are no efficient public policies on these three sets of suggestions, the group of researchers in Chemistry teaching has been active and has achieved relevant results. The most recent state and national curriculum guidelines enabled High School to have an identity and showed ways that may be followed by Chemistry teachers all over the country, considering regional particularities. To enable teachers to play their new roles, pre-service and in-service teacher education programs have been supported by research groups in Chemistry teaching, which have intertwined teaching and research (MESQUITA; MARTINS; LIMA, 2023). Besides, research groups have developed didactic material and their participation in the evaluation of textbooks promoted by the National Program of Textbooks has led to significant increase in the quality of the resources which are frequently used by teachers and students (RIGUE; SALES; DALMASO, 2022).

7 Conclusions

To teach Chemistry, Physics and Mathematics and show their interdependence is a great challenge since they are different and treat the world in distinct ways, but they maintain a

fundamental relation. As mentioned before, it may be due to the historical correlation between Chemistry and Mathematics, together with Physics teaching mostly based on the use of formulas and Chemistry teaching disconnected from everyday life and often abstract. Mathematics keeps being described by most students as "rocket science". Therefore, students end up thinking that one of them is a mere tool of the other or that one of them explains calculations and the other merely applies formulas.

It may make students either dislike any of the courses or like them due to reasons that are not significant. When students start High School, many students tend to dislike Physics and Chemistry, since they do not like Mathematics, either. On the other hand, many students end up enjoying Physics or Chemistry when they see that they are not exclusively full of mathematical concepts.

Such issue is worrisome because, even if Physics and Chemistry often depend on Mathematics, critical interpretation to analyze the world is fundamental. When the theory is taught, it is interesting to relate events under study to students' everyday events to show that Physics and Chemistry are everywhere, rather than only in textbooks, formulas and memorization activities. *After all, the one who memorizes does not learn!*

Therefore, Physics, Chemistry and Mathematics teaching must be re-considered. Regarding Chemistry and Physics, some teachers focus too much on theoretical teaching while others emphasize calculations. Other teachers are not able to relate theory to students' everyday life, a fact that makes them think that the courses are boring and disconnected from reality. However, Mathematics, Chemistry and Physics are extremely important courses even for the ones who do not intend to pursue careers in the areas. The three courses enable students to develop a critical analysis of the world, based on logical reasoning and connections among them.

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