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GLYCOGENESIS OR 'ANAEROBIC GLYCOGENOLYSIS'? UNDERSTANDING LEARNING PROCESSES IN A BIOCHEMISTRY CLASSROOM

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Guilherme Orsolon de Souza[1].

ABSTRACT
Considering theoretical and methodological aspects regarding learning as a process of signification, we examined how students mobilize knowledge before and after their experiences in a didactic unit that related the conceptual and contextual dimensions of glucose metabolism. Discursive Textual Analysis was applied to analyze and assist in the understanding of the texts produced as answers to contextualized and problematized questions about mitochondrial aerobic metabolism and muscle glycogenolysis. We noticed that previous knowledge was promptly activated and mobilized in order to give shape to the object of study. However, some gaps, forgetfulness and difficulties were present. Similarly, alternative conceptions also emerged as preexisting knowledge. Despite this, we understand them as new possibilities of anchoring for new interactive contexts and so that more interesting and proactive processes of (re)signification for students can be established in a biochemistry classroom.

Keywords: Biochemistry Teaching. Processes of Signification. Apprenticeship.

[1] Dr. in Sciences UFRuralRJ;
EBTT Professor of Biology – Federal Center for Technology Education Celso Suckow da Fonseca (CEFET/RJ), Valença Campus, RJ - Brazil –
E-mail: guilherme.souza@cefet-rj.br /
ORCID: https://orcid.org/0000-0003-0651-585X.
LATTES: http://lattes.cnpq.br/8615679818466715

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INTRODUCTION

LEARNING BIOCHEMISTRY AS A PROCESS OF SIGNIFICATION

Science Education has been, since the 90s of the twentieth century, proposing to rethink theoretical-methodological perspectives on teaching-learning processes in Science for Elementary, Secondary and Higher Education. For the Teaching of Biochemistry it was no different, since the end of the 70s, the Brazilian Society of Biochemistry and Molecular Biology (SBBQ) proposed to discuss the need to take a new, more careful, critical and reflective look at the teaching-learning process that occurs in this field of knowledge, but with the first works published only from the 90s onwards (Loguercio; Souza; Del Pino, 2007).

Biochemistry is often characterized as an area of greater learning difficulty, as it involves complex subjects that occur at the cellular and molecular level and, most of the time, abstract, making it difficult to represent, understand, associate and integrate the contents themselves and with different contexts, thus compromising the integrated education of students at different levels of education (Sabino et al., 2009; Schimidt et al., 2014; Scatigno; Torres, 2016). Specifically in higher education, some problems are registered, such as: large volume of information to be worked on in a reduced workload; the didactic tools used do not always address the contents satisfactorily; high rates of failure and damage to the interdisciplinary character that biochemical content performs with other areas of knowledge, with other disciplines, with professional practice and with the daily lives of students (Albuquerque et al., 2012; Farkuh; Pereira-Leite, 2014; Cavalcante et al., 2023).

To understand the above context and the need for a (re)construction of the teaching-learning process, it is first necessary to understand that this perception of students reflects the way in which, in recent decades, school curricula have been constructed, organized and presented, in general, having as reference only the conceptual dimension of the disciplines, as occurs in the area of Science Teaching and, consequently, also in the Teaching of Biochemistry (Muenchen; Delizoicov, 2014). From this perspective, the learning process is anchored in a transmission-reception model with an emphasis on memorization and subsequent reproduction of knowledge , as Coll (1994, p. 148) illustrates "[...] This is what happens when he learns in a purely memoristic way and is able to repeat them or use them mechanically without understanding at all what he is saying or what he is doing."

For example, themes that deal with different metabolic pathways should be understood in an integrated, associated way in order to achieve some understanding of the complexity of enzymatic reactions, transformations and interconnections between biochemical pathways, but which are often taught separately, individualized (Albuquerque et al., 2012; Farkuh; Pereira-Leite, 2014; Scatigno; Torres, 2016; Cavalcante et al., 2023). This individualization of knowledge generates such learning difficulties reported by students because it weakens their analytical-associative capacity, their autonomy and self-esteem, as when they are confronted with analysis, interpretation, associations between information and decision-making in a critical, collaborative way in a world permeated by scientific, technological, social issues, etc. (Machado; Orsolon-Souza, 2018).

Consequently, as teachers in the area of Science Education, we question ourselves about how to structure a teaching-learning process that is not limited only to the memorization/reproduction of scientific concepts and phenomena, but takes into account, and incorporates into this scientific dimension, other aspects such as the relationship between different disciplines and fields of knowledge, social and economic contexts, etc., for the training not only of professionals, but of citizens who position themselves in a scientific and technological world in a critical and safe way (Machado; Orsolon-Souza, 2018). The answer to our concerns is not (and will not be!) ready, it is a pedagogical path that has constantly been translated into (re)thinking our teaching practice and (re)constructing the classroom as a dialogical space where more interesting learning processes can be established, at the same time that some scientific knowledge, that are expressed in the curricular contents to be taught, can be apprehended in a relevant way by students (Oliveira; Adam; Amaral, 2023).

In view of this, when we seek pedagogical possibilities, which add epistemological and methodological dimensions, we understand that learning in Biochemistry also incorporates different fields of knowledge, connections with other disciplines, different social, economic, environmental contexts, etc., going beyond the merely conceptual or content-based perspective (Loguercio; Souza; Del Pino, 2007). According to Coll (1994, p. 148) "The student learns any content – a concept, an explanation of a physical or social phenomenon, a procedure to solve a certain type of problem, [...] – when it is capable of attributing a meaning to it." Therefore, from the perspective of modifying this condition and restructuring the perception of the teaching-learning process that incorporates this complexity, we make use of a theoretical-methodological matrix that situates learning as a

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process of construction of meanings, that is, that envisions viable ways for concepts, phenomena and the interconnection between biochemical pathways to be constructed in a meaningful way by students (Loguercio; Souza; Del Pino, 2007; Moreira, 2011; Gámez; Ruz; Lópes, 2015; Scott; Rocha, 2016; Felicetti; Batista, 2023).

Therefore, in our theoretical-methodological matrix, in order to build a more integrated learning, in which students are more stimulated, it is necessary that there is a relationship between their previous knowledge and the new knowledge worked on in more dynamic and proactive contexts in the classroom (Sutton, 1996; Felicetti; Batista, 2023). In other words, a prior or subsuming knowledge is characterized as a "[...] specific knowledge, existing in the structure of knowledge of an individual, which allows to give meaning to the new knowledge that is presented to him or discovered by him." (Moreira, 2011, p. 14).

In this sense, students, in order to give meanings, can present alternative conceptions (also known as intuitive, spontaneous conceptions or conceptual errors) arising from their interactions with the environment in which they live and/or the exchange of knowledge with other people, as forms of prior knowledge (Pietrocola, 2005; Fig tree; Rocha, 2011). In this case, they are understood as the knowledge that students have about natural phenomena, spontaneously mobilized to make sense of problem-situations in a learning process and, most of the time, do not agree on scientific concepts or laws (Leão; Kalhil, 2015). However, they can function as relevant knowledge or as the subsumers available in the students' cognitive structure, under which the new knowledge to be worked on can be anchored, helping to transpose rote learning to meaningful learning (Krause; Sheid, 2018).

In view of this, we also consider that the construction of meanings of a scientific and biochemical order is intrinsically associated with thought, language and experience, that is, with the "[...] development of ways of observing, and ways of relating to reality; that this implies and presupposes the ways of thinking, the ways of speaking and the ways of doing, but above all, the ability to bring all these aspects together". In this sense, the learning process can generate some tension, conflict, as well as sharing and convergence that help the understanding of the learning process itself and the (re)construction of knowledge in a social, interactive context (Arcà; Guidoni; Mazzoli, 1990, p. 24-25).

Thus, we proposed to elaborate and apply a didactic unit that would encompass the complexity between the conceptual and contextual dimensions of scientific and biochemical knowledge, and that the learning process would occur in a meaningful way, as proposed by Zabala (1998). According to this author, didactic units are characterized as theoretical-practical activities developed in a structured and articulated way with the objective of building some learning. Therefore, the didactic unit needs to involve the rescue of previous knowledge and possible associations with the new knowledge worked, the curricular contents need to be developed in a meaningful way and adjusted to the level of development of the students and the theoretical-practical activities need to motivate learning, generating self-esteem and autonomy during the learning process itself.

The structuring of the didactic unit was made from Delizoikov's Three Pedagogical Moments (Delizoicov; Angotti; Pernambuco, 2002) characterized as: Initial problematization when they are stimulated to present their perceptions, their previous knowledge about a certain body of knowledge; Organization of knowledge when this same body of knowledge needs to be activated and worked on in a structured way to assist in its understanding and initial problematization; Application of knowledge when the body of knowledge worked on in the previous stages is systematized so that they analyze, interpret and propose questions so that real situations and/or contexts can be understood by the same body of knowledge.

To this end, we worked with students of the General Biochemistry discipline, belonging to the cycle of mandatory disciplines of the Food Engineering course at CEFET/RJ – Valença. It is recurrently indicated by students as one of the most difficult to learn, which is why we applied our didactic unit that addressed, through various theoretical-practical didactic activities, the curricular contents on glucose metabolism (glycolysis, Krebs cycle, electron transport chain, glycogenolysis, glycogenesis and gluconeogenesis).

Thus, our objective was to analyze written sequences in order to examine how students activate and mobilize knowledge, concepts, biochemical pathways and their interconnections regarding mitochondrial aerobic metabolism and glycogen metabolism before and after the development of the aforementioned didactic unit.

METHODOLOGICAL PATHS

NATURE OF THE RESEARCH

The work was carried out from a qualitative perspective because it was concerned with the answers, propositions, indications of the students during the development of the activities and the realization of the proposed questions (Víctora; Knauth; Hassen, 2000). Qualitative analysis focuses on a reality that cannot be quantified, dimensioned, because its basic premise is the interpretation of phenomena, the attribution of meanings and the

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natural environment as direct principles to investigate or explore the understanding of a given culture and the universe in which it focuses "[...] because the human being is distinguished not only by acting, but by thinking about what he does and by interpreting his actions within and from the reality lived and shared with his fellow human beings." (Minayo, 2009, p. 21).

In this way, the professors-researchers have a relevant attribution in the process and the meanings constructed became the main axis of the study through the observation of the participants and the direct and personal contact with the researched universe, with an approach to understanding the perspective of the participants. Thus, we understand that the present study addresses an interpretation, an analysis, and, although we have made an effort to group real and objective data about life and the universe of research, inevitably, our abstraction and subjectivity were present throughout the work (Bogdan; Biklen, 2010).

THE PLACE AND SUBJECTS OF THE RESEARCH

We applied the work in a class with five students (three female and two male) enrolled in the semester of 2022/2 in the General Biochemistry discipline of the bachelor's degree course in Food Engineering at the Celso Suckow da Fonseca Center for Technological Education - CEFET/RJ, located in Valença, RJ, Brazil. The students were residents of Valença and other municipalities in the State of Rio de Janeiro. The information was recorded between October and December 2022 during classes that took place twice a week, lasting an hour and a half each. According to the current curriculum, the discipline is characterized by four times of classes/weekly theoretical credits.

We emphasize that, recurrently, this discipline has a reduced number of enrollments due to the high retention in the previous disciplines directly / indirectly related (General Biology, General Chemistry and Experimental Chemistry) and/or in the prerequisites (Organic Chemistry 1 and 2).

The Informed Consent Form (ICF) was prepared and delivered to each student, highlighting the objectives of the research, justification, an introduction on the methodological development of the work, on the teacher-researcher, ethical aspects, confidentiality, storage and confidentiality of the data and the participants involved, among others, therefore, all students signed the Informed Consent Form and participated in the research.

THE CONSTRUCTION OF THE DIDACTIC UNITS

We will define 'didactic units' as a group of activities with theoretical and/or practical characteristics that must be worked on in a biochemistry classroom in a structured and articulated way with the objective of achieving some desired learning process. The themes used dealt with glucose metabolism: cellular aerobic respiration (glycolysis, Krebs cycle and electron transport chain/oxidative phosphorylation), glycogenolysis, glycogenesis and gluconeogenesis.

Didactic units should cover some educational parameters or objectives, such as: (i) the recording and retrieval of previous knowledge and the promotion of correlations with new knowledge developed in the classroom; (ii) the contents/subjects/themes must be presented in a meaningful way and appropriate to the students' level of understanding; (iii) theoretical-practical activities need to motivate them in the learning process, awakening self-esteem, autonomy, collaborative attitude and critical thinking in the face of issues related to biochemistry and the scientific universe (Zabala, 1998). To this end, the didactic units were divided into three distinct stages following Delizoicov's Three Pedagogical Moments, as follows: (Delizoicov; Angotti; Pernambuco, 2002).

INITIAL PROBLEMATIZATION - STAGE 1: RESCUING PREVIOUS KNOWLEDGE

Stage developed through questions and/or situations that encouraged students to expose their perceptions, that is, it helped in the registration of previous knowledge about the subjects that were dealt with in previous disciplines with similar themes. Specifically, we constructed a pre-test containing two discursive questions that addressed some step(s) of the glucose metabolism pathway. The first requested connections between the stages of mitochondrial aerobic metabolism, and the second, discussions about the degradation of muscle glycogen.

ORGANIZATION OF KNOWLEDGE - STAGE 2: WORKING ON BIOCHEMICAL CONTENTS

We structured this stage through a body of knowledge that needed to be activated to assist in the understanding of the mandatory contents of the General Biochemistry discipline and the initial problematization. To this end, we activated and worked on the theme of glucose metabolism through schemes, texts, illustrations that presented and related the cycles, their reactions and/or the enzymatic mechanisms involved, theoretical and expository classes, group discussions through contextualized and/or problematized exercises to fix knowledge. We emphasize that texts, images, diagrams, illustrations, etc. used were also available in the textbooks present in the library of the Teaching Unit for student access. They are important and recurrent didactic resources in Science Teaching when direct observation or analysis of the object of study is not possible (Krasilchik, 2016).

APPLICATION OF KNOWLEDGE - STEP 3: ANALYZING BIOCHEMICAL CONTEXTS

In this stage, the sets of knowledge worked by the students in the two previous stages were systematized so that they could analyze and interpret real situations and/or contexts that could be understood by the same body of knowledge. In this perspective, we used contextualized and/or problematized texts associated with questions that requested the application of the knowledge worked in the didactic unit during the semester. This activity was called case study, in which students needed to interpret, discuss and make propositions in an analytical and critical way to certain situations, thus applying a set of biochemical knowledge related to glucose metabolism.

In the first case study, we made available the text Study relates pesticide use to symptoms of Parkinson's disease (Gerhardt, 2000) which presented a possible relationship between the substance rotenone ($C_{23}H_{22}O_6$) and degenerative diseases. The students were asked to construct a text that explained possible consequences for mitochondrial aerobic metabolism when rotenone blocks the oxidation of NADH (nicotinamide adenine dinucleotide) by the flavoprotein and, consequently, the transfer of electrons to the protein subunit with series of iron-sulfur centers and to Coenzyme Q/CoQ (also known as Ubiquinone/Q) of Complex I (NADH-CoQ oxidoreductase complex) of the chain electron transporter (Campbell; Farrell, 2008).

In the second case study, we used the text Glycemic control through physical activity: it is possible' (Arantes, 2021) which contextualized and proposed relationships between diet, physical activity, carbohydrate metabolism (glycolysis, glycogenolysis, and gluconeogenesis), insulin control, and quality of life. The students needed to discuss specific points of the text such as: (a) the mobilization and increase in the availability of glucose even though the insulin supply is in low concentration; (b) under normal physiological conditions, which biochemical pathway could be triggered when blood glucose concentration is increased; (c) on the route of removal of muscle lactate.

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ON THE CONSTRUCTION AND APPLICATION OF PRE- AND POST-TESTS

The tests helped us to investigate, record and analyze the construction of learning processes, the focus of the present study. As already mentioned above, the application of the test before the development of the didactic unit was intended to record, mainly, the students' previous knowledge (Appendix 1). Therefore, following our objective of analysis and comparisons from a qualitative perspective, we chose to apply the same test after the development of the didactic unit, as it made it possible to perceive the activation, mobilization and/or association of a body of biochemical knowledge for the resolution and (re)structuring of new answers to the questions. In both tests, it was not allowed to consult any textual or imagery material.

The test was composed of two discursive questions, the first addressed mitochondrial aerobic metabolism from the interpretation of a partial image/scheme, and had as an expected answer an argument about the interaction between the reduced molecules NADH (nicotinamide adenine dinucleotide) and $FADH_2$ (flavin adenine dinucleotide), formed in the Krebs cycle, the Complexes I (NADH-CoQ oxidoreductase complex) and Complex II (Succinate-CoQ oxidoreductase complex) of the electron transport chain, respectively (Campbell; Farrell, 2008).

The second question was contextualized from a scientific note on the mutation of a gene that promoted the accumulation of glycogen in pig muscle and had as an expected answer a discussion on the blockade of the muscle glycogen degradation pathway (glycogenolysis).

DATA RECORDING AND ANALYSIS

To record and analyze the data in a qualitative way, we used the texts prepared by the students to answer the questions of the pre and post-tests. These were called the sequences written and analyzed through Discursive Textual Analysis (DTA), which should be understood as a

> [...] analysis of qualitative information to produce new understandings of texts and discourses. [...] The ATD seeks to deepen the researcher's knowledge of the deconstructive process called unitarization, a recursive process of diving into the meanings attributed to the texts under analysis. (Sousa; Galiazzi, 2018, p. 800).

Consequently, we chose to present the sequences written in the discussion of the work (Tables 1 and 2). Thus, in order to maintain a more organic analysis, possible

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grammatical, spelling, semantic errors, etc., were kept in full so that they could reflect different contexts and experiences. We use the code - Student(a)$^{\text{year/academic semester}}$ - to identify students from the moment they enter the Educational Institution.

MOBILIZING AND ARTICULATING PREVIOUS AND NEW KNOWLEDGE

To assist and organize the analysis, we present the results and the discussion in three sections. In the first, the activation, mobilization of previous knowledge and its (re)structuring after the development of the didactic unit is evidenced. In the second, these movements are repeated, but the proposition of alternative conceptions stands out, that is, knowledge not expected for the (re)construction of the answers. In the third section, we set out to understand the construction of learning processes in a biochemistry classroom.

RESCUING AND (RE)CONSTRUCTING KNOWLEDGE ABOUT MITOCHONDRIAL AEROBIC METABOLISM

The first question dealt with the partial presentation of a scheme that indicated the electron transport chain and omitted the beginning of its functioning, i.e., the arrival of reduced molecules of NADH and FADH2 in Complexes I and II of the mitochondrial inner membrane, respectively. The students were asked to address which pathway was being presented and which were suppressed in order to build a discussion about the interconnection between pathways of mitochondrial aerobic metabolism – glycolysis, the Krebs Cycle and the electron transport chain. To assist in the analysis and discussion, the written sequences constructed by the students in the pre- and post-test were presented comparatively in Table 1.

When analyzing the written sequences of the pre-test, we observed that three students had difficulties in identifying the pathways represented and suppressed in the scheme, totally or partially departing from what was requested in the question: Student 2021/1 did not answer; Student 2019/2 signaled that the Krebs cycle would be presented in the scheme ("I think the metabolic pathway represented is the Krebs cycle.") and Student2019/2 recognized only the cytoplasmic organelle ("mitochondria").

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Table 1: Comparison between the answers to the first question of the Pre and Post-test. Theme: mitochondrial aerobic respiration. Expected answer: interconnections between glycolysis, the Krebs cycle and the electron transport chain. Valença/RJ, 2024.

Student2021/1	Pre-test: The aerobic pathway, because the second structure is generating electrons to form water with H+ and O2. I think. Post-test: The metabolic pathway is the glycolytic pathway, more precisely its third phase, the electron transport chain. The suppressed part is made up of glycolysis which from the glucose molecule produces 2 pyruvates, 2 ATPS and 2 NADH and the Krebs cycle which produces 2 ATPs, 6 NADH, 2 FADH, from the 2 pyruvates produced in glycolysis.
Student2021/1	Pre-test: Blank. Post-test: The glycolytic pathway, the scheme presents only the electron transport chain, but it is initially necessary that glycolysis and the Krebs cycle occur, in order to "cause" this chain.
Student2020/1	Pre-test: The electron transport chain occurs at the crest of the mitochondria and is the phase of the Krebs cycle in which large ATP production occurs. I remember that NADH and FADH carry something to the proteins of the inner membrane (I think it's H+ and ATP)." Post-test: The schematic represents the electron transport chain, which is part of the glycolytic pathway. In this representation, the molecules of NADH and FADH2 are suppressed, which are the structures responsible for transporting H+ protons to protein complexes 1 and 2, respectively.
Student2019/2	Pre-test: I think the metabolic pathway represented is the Krebs cycle. Post-test: The metabolic pathway in question is the Krebs cycle, the suppressed part is the formation of NADH during the cycle process.
Student2019/2	Pre-test: mitochondria Post-test: Phosphorylative oxidation, ATP and H2O production occurs.

Source: Survey data.

In an uncertain and unstructured way, two students came closer to what was expected. Student2021/1 indicated the biochemical pathway more assertively, but did not point out the suppressed part of the scheme ("The aerobic pathway, because the second structure is generating electrons to form water with H+ and O2. I think.")element. Aluna2020/1 proposed a more elaborate construction ("The electron transport chain occurs at the crest of the mitochondria [...] I remember that NADH and FADH carry something to the proteins of the inner membrane (I think it's H+ and ATP)."), but suggested the Krebs cycle as the route of greatest energy production ("[...] and it is the phase of the Krebs cycle in which large ATP production occurs. [...]")element. Regardless of whether or not the proposals are close to the objective of the activity, these initial movements refer to an active search for a group or even a "[...] specific knowledge, existing in the structure of knowledge of an individual, which allows giving meaning to the new knowledge that is presented to him [...]" (Moreira, 2011, p. 14). In other words, it is possible to see the search for knowledge that can be correlated with, or have some approximation with, the biochemical knowledge that was initially required (Sutton, 1996).

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However, the above context was changed when we analyzed the written sequences related to the post-test. We recorded more elaborate, structured textual constructions with better scored biochemical connections, such as those carried out by Student2021/1, Student2021/1 and Student2020/1 that not only identified mitochondrial aerobic metabolism as a whole, but also associated the suppressed pathways (glycolysis and Krebs cycle) and described them in more detail. They even explained the amount of molecule produced by glycolysis and the Krebs cycle as done by Student2021/1 ("[...] The suppressed part is composed of glycolysis which from the glucose molecule produces 2 pyruvates, 2 ATPS and 2 NADH and the Krebs cycle which produces 2 ATPs, 6 NADH, 2 FADH, from the 2 pyruvates produced in glycolysis.").

Two other interesting examples of this textual (re)structuring refer to Aluna2019/2, who had previously identified the schema as the Krebs cycle, apparently reelaborated her answer, now identifying it as the suppressed part ("[...] the deleted part is the formation of NADH during the cycle process.")element. In contrast to the simple answer given in the pre-test, Student 2019/2 proposed a slightly more structured and more assertive textual construction about oxidative phosphorylation and its energy production shown in the scheme ("Phosphoryl oxidation, ATP and H_2O production occurs."). Because he did not call the teacher during the activity, it was not clear why he did not describe and/or indicate the suppressed path, whether due to forgetfulness, ignorance and/or misunderstanding of the statement.

We note, therefore, that they readjusted the object of study by proposing more assertive interconnections between biochemical pathways that were initially non-existent or weakly associated, in this way, the students achieved a greater and better approximation of the objective of the activity, probably because they also mobilized and related the knowledge experienced in the didactic unit (Moreira, 2011; Gámez; Ruz; Lópes, 2015; Scott; Rocha, 2016).

Similar to what was recorded in this section, the rescue, the (re)construction of concepts and the connections between biochemical pathways were again evident in the next section, when the students, with the help of the teacher's mediation, extrapolated what was requested in the question about muscle glycogenolysis by activating, associating and using unexpected knowledge about biochemical pathways, as alternative conceptions, leaving the object of study more elaborate and complex.

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The second question was contextualized from a short scientific note that addressed the mutation of a gene that promoted the accumulation of glycogen in pig muscle. We asked the students to make an argument about the biochemical pathway that was being affected by the genetic mutation in order to discuss the blockade of the muscle glycogen degradation pathway (glycogenolysis). The written sequences of the pre- and post-test were also presented comparatively (Table 2).

Table 2: Comparison between the answers to the second question of the Pre and Post-test. Theme: glycogen metabolism. Expected answer: approaches to muscle glycogenolysis. Valença/RJ, 2024.

Student2021/1	Pre-test: The anaerobic route, since the post-mortem metabolism does not consume all the glycogen it could consume. I think! Post-test: The glycogenolysis pathway, the degradation of glycogen stores by the action of glycogen phosphorylase. The glycogen that is in the muscle should function as a reserve and be degraded to glucose-1-phosphate and then to glucose-6-phosphate. If glycogen is accumulating, this pathway is being impaired. Another alternative is that glycogenesis may be overactivated. Glycogenesis is a pathway of glycogen synthesis from glucose, performed by glycogen synthase. A disjunction could be consuming glucose in glycogenesis, even without excess gliosis, causing excess muscle glycogen.
Student2021/1	Pre-test: Blank Post-test: The pathway that may be affected is glycogenesis, which is the pathway responsible for the formation of glycogen to be stored; or also the life of glycogenolysis which is related to glycogen degradation. That is, this gene may be causing this accumulation of glycogen through a large production of glycogen where the body is unable to degrade it, or else the production of stored glycogen is the same, but the gene affects the degradation pathway of this.
Student2020/1	Pre-test: Pigs have a high percentage of fat in the body, so I think the metabolic pathway affected is the one that uses lipid molecules to start the cycle (I don't know the name of the pathway). In addition, glycogen is a very large sugar molecule, I don't know if it is broken down into glucose, so the metabolic pathway could not be the Krebs cycle. Post-test: Glycogen is synthesized from glucose that is in excess in the body. Thus, in order for glycogen to accumulate, it is possible that the mutated gene alters the functioning of the glycolytic pathway and thus the glucose that would be degraded in aerobic respiration is alternatively converted to glycogen. It can also be thought that the accumulation of glycogen is the result of the non-degradation of this polysaccharide. Thus, the RN gene may have affected the glycogenolysis pathway.
Student2019/2	Pre-test: I think the pathway affected is the glucose cycle. Post-test: The metabolic pathway that can be affected is that of DNA, because once modified, it ends up deregulating its functioning and the correct fit of its forms, which can cause the creation of cells that the body does not recognize and generate a generalized deregulation of all other metabolic pathways in the body, which can block the passage of oxygen to the muscle and generate lactic fermentation, which makes the quality of the meat poor.

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Student2019/2	Pre-test: Some pathway related protein synthesis. Post-test: Via glycogenesis, it creates a buildup of glucose in the muscle preventing glucose (G6P) from entering the endoplasmic reticulum and not producing glucose that would otherwise follow in the bloodstream.

Source: Survey data.

Except for Student 2021/1 who again did not propose a text, apparently due to forgetting the information (but which was not clear because there was no manifestation/explanation in oral and/or written form by the student), the other students proposed different textual constructions. Two students deviated from what was expected in the question: Student 2019/2 presented a construct that involved protein metabolism ("Some pathway related to protein synthesis."); and Student 2021/1 suggested, without certainty or deepening, the anaerobic metabolism of glycogen ("The anaerobic pathway, since the post-mortem metabolism does not consume all the glycogen it could consume. I think!"). On the other hand, twostudents touch on the response that was expected. However, they also constructed their approaches in an uncertain way and without further details about the requested metabolism – muscle glycogenolysis – ("I think the affected pathway is the glucose cycle." Student2020/1; "[...] glycogen is a very large sugar molecule, I don't know if it is broken down into glucose, so the metabolic pathway could not be the Krebs cycle." Student2019/2).

During the performance and, later, in the post-test analysis, two important aspects were recorded. In the first of them, also analogous to the one recorded in the first question, it was possible to perceive better breadth and complexity of the answers constructed after their experiences in the didactic unit. As examples, Aluna2021/1, which had not initially answered the question, built a more comprehensive text connecting two distinct biochemical pathways. Similarly, Student 2019/2, who had moved away from the objective of the question, proposed a more assertive textual construction. However, this student and three other students (Student 2020/1, Student 2021/1 and Student 2021/1), activated and added an unexpected but biochemically valid/viable biochemical pathway to their responses. This mobilization of unexpected biochemical pathways characterized the second aspect that began to be observed by the professor at the time of the post-test.

According to the professor's report, three students (Student 2020/1, Student 2021/1 and Student 2021/1) called him during the resolution of the second question, indicating the possibility of approaching it from two distinct biochemical pathways: by blocking/non-degradation of muscle glycogen or by accumulating glucose due to its non-degradation by

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the glycolytic pathway. In response, the professor mediated the questioning by saying that, if there were biochemical possibilities, they could build their arguments with multiple approaches. Although the objective of the question was to construct a discussion about the blockade of muscle glycogenolysis, the professor authorized other approaches because he realized that the students had extrapolated the statement and, apparently, in a spontaneous, autonomous and proactive way (Leão; Kalhil, 2015), were mobilizing a broader body of biochemical knowledge through other interconnections between unexpected (such as alternative conceptions to what was requested), but biochemically valid and/or viable (muscle glycogenesis) (Pietrocola, 2005; Fig tree; Rocha, 2011).

For example, not only did they realize that it was a blockade of muscle glycogenolysis, as requested in the statement of the question ("[...] It can also be thought that the accumulation of glycogen is the result of the non-degradation of this polysaccharide. Thus, the RN gene may have affected the glycogenolysis pathway." Student[2020/1]), as they expanded their analyses and found a second possibility – an accumulation of glucose, resulting from non-degradation by the glycolytic pathway, would be generating an increase in muscle glycogenesis:

> [...] It is possible that the mutated gene alters the functioning of the glycolytic pathway and thus the glucose that would be degraded in aerobic respiration is alternatively converted to glycogen. (Student2020/1)
>
> Via glycogenesis, it creates an accumulation of glucose in the muscle, preventing glucose (G6P) from entering the endoplasmic reticulum and not producing glucose that would follow in the bloodstream. (Student[2019/2])

We also noticed that the idea of anaerobic metabolism of muscle glycogen degradation had once again been mobilized and presented ("[...] and generate a generalized deregulation of all other metabolic pathways in the body, which can block the passage of oxygen to the muscle and generate lactic fermentation, which makes the quality of the meat poor." Student[2019/2] - emphasis added). It is relevant to repoint that, apparently, the anaerobic metabolism of glycogen was also activated by Student2021/1 during the pre-test ("The anaerobic pathway, since the post-mortem metabolism does not consume all the glycogen it could consume. I think!" Student[2021/1] - pre-test – emphasis added), inducing him/her to some degree to think in ways different from the one requested in the question, possibly as another alternative conception (Pietrocola, 2005; Fig tree; Rocha, 2011), but which was not clear due to the lack of detail in the answer given and because he called the teacher only at the time of the post-test, when he questioned him only about the possibility

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of approaching glycogenesis. Thus, the teacher only realized this student's proposal when he performed the comparative analysis of the data, that is, after the students completed the post-test, making it impossible to mediate during the pre-test.

Understanding learning as a process under construction between students, teacher and object of study, in the next section we set out to understand how teacher mediation combined with didactic unity provided the rescue of previous knowledge and its relationship with the new biochemical knowledge that was intended to be worked on (Zabala, 1998; Delizoicov; Angotti; Pernambuco, 2002). We also realize that even the propositions of unexpected biochemical pathways for the resolution of the question, such as alternative conceptions, are valid movements because they can sometimes function as an anchor for new learning contexts (Moreira, 2011). Thus, once again mediated by the teacher, the classroom can once again be (re)constructed as an interactive space, where more interesting and proactive processes of (re)signification for students can emerge.

UNDERSTANDING SOME LEARNING PROCESSES IN A BIOCHEMISTRY CLASSROOM

The results obtained in the pre- and post-test, represented here by the written sequences, suggest that we think that the didactic unit was able to achieve its educational objectives as proposed by Zabala (1998). Once structured and articulated the conceptual and contextual dimensions of knowledge about glucose metabolism, more dynamic learning processes for the (re)signification of the object of study could take shape in our biochemistry classroom. However, in a learning process from the perspective of the construction of meanings, it is expected and understandable that students present gaps, difficulties or even forgetfulness of a given body of knowledge, because learning as a process of signification "[...] it is not synonymous with 'correct' learning. [...] and it is not the one we never forget." (Moreira, 2011, p.24, emphasis added).

From this perspective, we need to consider that they have been immersed in the undergraduate course for at least three semesters, so apparently it is a matter of seeking some biochemical knowledge supposedly learned in previous experiences. Thus, the rescue of previous knowledge and the movements that were carried out by the students to rethink and readjust the object of study were characterized as a process of attributing meanings, new constructions, or even the choice of one among some meanings or some alternative conceptions, such as pre-existing subsumers in the cognitive structure of the students (Moreira, 2011; Gámez; Ruz; Lópes, 2015; Krause; Sheid, 2018).

For example, in the first question, students may be activating knowledge previously worked on in the General Biology discipline, taken in the first semester of the course, which dealt in detail with the anatomy of mitochondria and the biochemical pathways involved in mitochondrial aerobic metabolism, propositions that brought them closer to the objective of the activity. In the second question, apparently, the same search movements in other disciplines led to the emergence of unexpected biochemical pathways as alternative conceptions, as done by Student2020/1, Student2021/1 and Student2021/1 with glycogenesis as an additional explanatory pathway, or done by Student2021/1 and Student2019/2 as the anaerobic metabolism of glycogen as an alternative pathway to explain the same situation proposed.

Thus, the proposition of glycogenesis[2] may be related to the fact that it was an anabolic biochemical pathway studied in a contextualized and problematized way as was foreseen in the didactic unit (Zabala, 1998; Delizoicov; Angotti; Pernambuco, 2002), which must have generated some comfort in mobilizing her, associating her and adding her to her answers. We consider that these movements partially brought them closer to the objective because, supposedly, the students made a simple, objective and direct association with some physiological context in which there was a greater supply of blood glucose (after a diet rich in carbohydrates, for example) which, not being used for glycolysis, can be directed to muscle glycogen synthesis, making it a biochemically viable/valid pathway, Especially when thinking about a context of increase, maintenance and/or non-use of muscle glycogen

On the other hand, we intuit that the proposition made by Student2021/1 and Student2019/2 about the anaerobic metabolism of glycogen as a consequence of gene mutation, may be related to the fact that the statement also addresses the quality and production of meat and its derivatives, which is a theme in which biochemical knowledge is applied to a process of production and improvement of meat and its derivatives and which is worked on in the course of degree in question (Raw Materials of Animal Origin, 3rd period, for example). It is worth clarifying, therefore, that even though it is a biochemically

[2] Explanatory note for a better understanding of glycogenesis: by the action of insulin, when the availability of glucose becomes high and unnecessary as an energy source for glycolysis, the muscle cell can synthesize glycogen. Briefly, to start the synthesis process, a primer composed of four glucose residues linked to the protein glycogenin is required. From this point, the enzyme glycogen synthase catalyzes reactions between UDP-glucose molecules (uridine diphosphate glucose) and glycogen through a α(1→4) bond elongating the chain. The branching enzyme moves portions with seven glucose residues from the end of a growing chain so that there are branching points through α(1→6) bonds, making the glycogen structure increasingly complex and branched. (Campbell; Farrell, 2008, p. 596-598).

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viable/valid pathway, in these propositions the departure from the objective proposed by the professor occurred because in the anaerobic metabolism of glycogen[3], a catabolic process would be occurring, due to oxygen deficit, in the attempt to maintain the homeostasis of skeletal muscle tissue, especially in relation to the production and supply of energy in the form of ATP (adenosine triphosphate) (Pardi et al., 2005; Pereda et al., 2005), and not an accumulation of glycogen as reported in the statement of the question.

In view of this, it is important to emphasize that although these movements of (re)signification sometimes appear in an uncertain, fragmented way, which sometimes distanced them and brought them closer to what was expected, it was possible to perceive that they were not just any knowledge, that it is not an empty search or exempt from what already exists, rather, the activation of a set of knowledge with some closer relationship to what was requested, converging to a process of attributing meanings (Sutton, 1996). This mobilization, (re)organization and association between pre-existing and new knowledge is done by "[...] an interactive process in which the new gains meanings, integrates and differentiates itself in relation to what already exists [...]", transforming itself into an increasingly complex knowledge and allowing its relationship with other more elaborate knowledge (Moreira, 2011, p. 26).

Considering learning as a process under construction, although the propositions about muscle glycogenesis and anaerobic glycogen metabolism were a movement that distanced them, partially or totally, from the objective that the teacher intended to achieve with the activity, it is noted, on the other hand, that a new opportunity for learning and (re)signification was presented because

> When the subject attributes meanings to a given knowledge, interactively anchoring it in previous knowledge, learning is meaningful, regardless of whether these are accepted in the context of some teaching subject, i.e., whether the meanings attributed are also contextually accepted, in addition to being personally accepted. The well-known alternative conceptions, so researched in the area of science, are usually significant learning (and, therefore, so resistant to conceptual change). For example, if a person believes that in summer we are closer to the sun and in winter

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[3] Contextualized note on the 'anaerobic metabolism of glycogen': from the perspective of the Food Engineering course, this metabolic pathway is located in the area of 'food technology of animal origin' and is studied to improve the quality of food products - production of meat and derivatives - for example. Therefore, in animal slaughter there is a lack of blood circulation caused by bleeding, the oxygen supply to the tissues ceases and muscle glycogen reserves are used to generate glucose and energy (ATP) by the process of anaerobic glycolysis to maintain the homeostasis of skeletal muscle tissue. As a consequence, there will be formation and accumulation of muscle lactic acid, decrease in intracellular pH and interruption in the elimination system of products from cellular metabolism. Thus, intense chemical and physical modifications occur (irreversible muscle contraction and null extensibility of muscle fibers) characterizing *rigor mortis* or cadaveric rigor, causing the transformation of muscle into flesh or the '*post-mortem* change of muscle' (Pardi et al., 2005; Pereda et al., 2005).

> farther away, thus explaining the seasons, this may be significant to him, although it is not the scientifically accepted explanation. (Moreira, 2011, p. 24, emphasis added)

We understand that this knowledge or this pre-existing subsumer was activated and mobilized, probably, by the dynamic and contextualized character brought by the way the didactic unit was constructed and applied. However, it is not a limiting factor in our learning process because it can serve as an anchor under which the teacher can, at later times, unfold the conceptual change through the structuring and development of new theoretical-practical activities. In this way, helping students such as Student 2019/2, Student 2020/1, Student 2021/1 and Student 2021/1 to rethink and (re)construct in a more assertive way the relationship between the concept, the process and the context in which glycogenesis occurs and, mainly, the anaerobic metabolism of glycogen (Leão; Kalhil, 2015; Krause; Sheid, 2018).

We reiterate, once again, the importance of the positioning and the mediating movement carried out by the teacher when he authorized, during the post-test, that the students use different approaches (even characterizing alternative conceptions) to solve the second question, as he realized that at that moment, some actions of autonomy, self-esteem, and a critical-reflective position were also emerging, to position themselves and indicate a new set of knowledge biochemists to (re)structure their responses (Zabala, 1998; Delizoicov; Angotti; Pernambuco, 2002). It is, therefore, about the importance and need of a mediation process for the construction of meanings in the classroom - students, teacher and object of study in an interactive and constructive context - which culminated in new (re)significations by the students, making the object of study more complex. The cognitive movements between what the student already knows and what is being worked on in the classroom, the concept ceases to be the central, main element, and also involves the complexity of an individual who is in the world and how he relates to it (Machado; Orsolon-Souza, 2018).

Therefore, the movements made by the analysis students, the search for similarities and differences and the proposals for interconnections between different biochemical pathways, through a propositional positioning to elucidate and readjust the relationship between concepts and contexts, brought them closer to a better and greater understanding of the biochemical pathways themselves and of the metabolic processes, the expansion of learning to other skills such as the development of written language and, in general, of

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analytical-associative thinking, as well as, intrinsically, the development of attitudes and values that make up a variety of competencies necessary to face the world through scientific and citizen education (Gámez; Ruz; Lópes, 2015; Krasilchick, 2016; Scott; Rocha, 2016).

Finally, these movements of (re)constructions and/or (re)significations carried out by the students recorded here, may be reflecting different ways in which they developed the ways of thinking, the ways of speaking, the ways of doing and, most importantly, the potential of associating all these aspects in order to resignify, to give shape to the object of study. This suggests reflecting and considering thought, language and experience in the Teaching of Biochemistry for the (re)structuring of a teaching-learning process that considers the complexity between the conceptual and contextual dimensions of scientific knowledge in Science Education (Arcà; Guidoni; Mazzoli; 1990).

CONSIDERATIONS ABOUT THE TEACHING-LEARNING PROCESS AND THE BIOCHEMISTRY CLASSROOM

Our proposal for understanding learning processes in a Biochemistry classroom aimed to record and verify how students' knowledge was activated before and after the development of a didactic unit on glucose metabolism.

After analyzing the written sequences, it was possible to perceive that the previous knowledge is mobilized by the students, explaining and projecting, even, some alternative conceptions, in order to give shape to the object of study (Pietrocola, 2005; Fig tree; Rocha, 2011; Lion; Kalhil, 2015; Krause; Sheid, 2018). However, at first, we observed in the pre-test that, even if some knowledge had already been worked on in previous disciplines, apparently there is a tendency to present gaps in the body of knowledge worked, forgetfulness or difficulty in the construction of concepts and/or interconnections between the main biochemical pathways requested in the questions. This is expected and understandable when investing in learning processes based on the construction of meanings (Moreira, 2011).

However, after the development of the didactic unit in which the basic/fundamental contents were exposed and worked through different didactic materials and theoretical-practical activities, the post-test indicated that, apparently, the gaps were filled and these forgetfulness/difficulties were probably being overcome as the students were activating and mobilizing a larger body of knowledge, more specific and broad, carried out in a mediated,

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(re)constructive context, giving new form and structure to the answers presented. Thus, we understand that such limitations tend to be overcome when students become accustomed to symbols and language of a scientific and biochemical nature, such as those present in books and various teaching materials (Krasilchik, 2016). Similarly, alternative conceptions can emerge and be projected onto responses. Subsequently, they serve as an anchor for new interactive contexts to be established in the classroom, the (re)construction of meanings and conceptual change can occur in an assertive and satisfactory way (Figueira; Rocha, 2011; Moreira, 2011; Lion; Kalhil, 2015; Krause; Sheid, 2018).

Thus, in order for more interesting learning contexts to take shape in the classroom, we reaffirm that the didactic units need to be built in a structured way, motivating the teaching-learning process, that previous and new knowledge can be related by the students and that aspects of self-esteem and autonomy can also be developed. To this end, we reiterate the relevance of a classroom as a dialogical space and of teacher mediation for the development of a meaningful learning process, in which other skills and competencies of a cognitive nature can be explored and expanded for a more assertive and comprehensive interpretation and understanding of the world. Equally relevant, the didactic units can and should be adjusted according to some specificity of contexts and/or curricula (Zabala, 1998; Delizoicov; Angotti; Pernambuco, 2002).

Finally, in order to solve new concerns and further reduce the perception of contents and/or disciplines considered to be of greater learning difficulty, we suggest that the teaching-learning process in Biochemistry should also consider other approaches not observed and worked on here, such as simulations (digital or not), investigative processes and experiments, within a dialogical context. mediated and meaning-making, in order to promote an increasingly deeper learning of biochemical knowledge and the integration between different biochemical pathways (Albuquerque et al., 2012; Farkuh; Pereira-Leite, 2014; Cavalcante et al., 2023). Thus, we recommend rethinking and reconsidering the specific conditions that are presented in a Biochemistry classroom in order to construct meanings of a broader scientific, technological and biochemical order (Machado; Orsolon-Souza, 2018).

REFERENCES

1. Albuquerque, M. A. C., Amorim, Â. H. C., Rocha, J. R. C. F., Silveira, L. de M. F. G., & Neri, D. F. de M. (2012). Bioquímica como sinônimo de ensino, pesquisa e extensão: Um relato de experiência. Revista Brasileira de Educação Médica, 36(1), 137-142.

2. Arcà, M., Guidoni, P., & Mazzoli, P. (1990). Enseñar Ciencia - como empezar: Reflexiones para una educación de base. Paidos.

3. Arantes, E. (2021, March 24). Controle glicêmico através da atividade física: é possível? [Web page]. Retrieved from https://beecorp.com.br/controle-glicemico-atraves-da-atividade-fisica-e-possivel/

4. Bogdan, R., & Biklen, S. (2010). Investigação qualitativa em educação: Uma introdução à teoria e aos métodos. Porto Editora.

5. Campbel, M. K., & Farrel, S. O. (2008). Bioquímica: Volume 3: Bioquímica metabólica (5th ed.). Thompson Learning.

6. Cavalcante, F., Fonsêca, C., Luz, E., Ramos, L., Silva, L., Soares, L., Lima, M. E., Albuquerque, P., & Albuquerque, P. (2023). Métodos ativos, experiência laboratorial e correlações clínicas articuladas ao aprendizado da Bioquímica: Inovando o método de ensino na Universidade de Pernambuco Campus Garanhuns. Revista de Ensino de Bioquímica, 21(1), 1-16. https://doi.org/10.16923/reb.v21i1.1016

7. Coll, C. (1994). Aprendizagem escolar e construção do conhecimento. Penso.

8. Delizoicov, D., Angotti, J. A., & Pernambuco, M. M. (2002). Ensino de ciências: Fundamentos e métodos. Cortez.

9. Farkuh, L., & Pereira-Leite, C. (2014). Bioquim4x: Um jogo didático para rever conceitos de bioquímica. Revista de Ensino de Bioquímica, 12(2), 37-54.

10. Felicetti, S. A., & Batista, I. de L. (2023). Educação inclusiva, interdisciplinaridade e teoria da aprendizagem significativa: Formação docente em Biologia. Revista Eletrônica Científica Ensino Interdisciplinar, 9(30). https://doi.org/10.21920/recei72023930398413

11. Figueira, A. C. M., & Rocha, J. B. T. (2011). Investigando as concepções dos estudantes do ensino fundamental ao superior sobre ácidos e bases. Revista Ciências & Ideias, 3(1), 1-21.

12. Gámez, C. M., Ruz, T. P., & López, M. A. J. (2015). Tendencias del profesorado de ciencias en formación inicial sobre las estrategias metodológicas en la enseñanza de las ciencias. Estudio de un caso en Málaga. Enseñanza de las Ciencias, 33(1), 167-184.

13. Gerhardt, I. (2000, November 06). Estudo relaciona uso de pesticida a sintomas de mal de Parkinson. [Web page]. Retrieved from https://www1.folha.uol.com.br/fsp/ciencia/fe0611200003.htm

14. Krasilchik, M. (2016). Prática de Ensino de Biologia (4th ed., 5th reimpressão). Editora da Universidade de São Paulo.

15. Krause, J. C., & Sheid, N. M. J. (2018). Concepções alternativas sobre conceitos básicos de física de estudantes ingressantes em curso superior da área tecnológica: Um estudo comparativo. Espaço Pedagógico, 25(2), 227-240.

16. Leão, N. M. de M., & Kalhil, J. B. (2015). Concepções alternativas e os conceitos científicos: Uma contribuição para o ensino de ciências. Latin-American Journal of Physics Education, 9(4), 4601-1 - 4601-3.

17. Loguercio, R., Souza, D., & Del Pino, J. C. (2007). Mapeando a educação em bioquímica no Brasil. Ciências; Cognição, 10, 147-155.

18. Machado, L. C. F., & Orsolon-Souza, G. (2018). Das inquietações às questões... aprendizagem e ensino de Biologia nas escolas. Latin American Journal of Science Education, 5, 1-9.

19. Minayo, M. C. de S. (2009). O desafio da pesquisa social. In M. C. de S. Minayo (Org.), Pesquisa Social: Teoria, Método e criatividade (16th ed., pp. 9-29). Vozes.

20. Moreira, M. A. (2011). Aprendizagem Significativa: A teoria e textos complementares. Editora Livraria da Física.

21. Muenchen, C., & Delizoicov, D. (2014). Os três momentos pedagógicos e o contexto de produção do livro "Física". Ciência e Educação, 20(3), 617-638.

22. Oliveira, T. M. R. de, Amaral, L. H., & Amaral, C. L. C. (2023). A prática pedagógica reflexiva em questão: Estudo de caso de uma escola brasileira. Revista Portuguesa de Educação, 36(2), 1-20. e23027. https://doi.org/10.21814/rpe.24860

23. Pardi, M. C., Santos, I. F. dos, Souza, E. R. de, Pardi, H. S. (2005). Ciência, higiene e tecnologia da carne (2nd ed.). Editora da UFG.

24. Pietrocola, M. (2005). Ensino de Física: Conteúdo, Metodologia e Epistemologia em Uma Concepção Integradora. Editora da UFSC.

25. Pereda, J. A. O., Rodríguez, M. I. C., Álvarez, L. F., Sanz, M. L. G., Minguillón, G. D. G. de F., Perales, L. de la H., & Cortecero, M. D. S. (2005). Tecnologia de alimentos: Alimentos de origem animal (Vol. 2). ARTMED.

26. Sabino, G., Amaral, F. C., Sabino, C. de V. S., & Kattah, L. R. (2009). Proposta de uma metodologia para o ensino da estrutura e função das proteínas na disciplina bioquímica. Revista de Ensino de Bioquímica, 1, 1-19. https://doi.org/10.16923/reb.v7i1.37

27. Scatigno, A. C., & Torres, B. B. (2016). Diagnósticos e intervenções no ensino de Bioquímica. Revista de Ensino de Bioquímica, 24, 29-51.

28. Schimidt, D. B., Heggendornn, L. H., Pereira, H. S., Vieira, V., & Aguiar-Alves, F. (2014). Mapas conceituais no ensino de bioquímica, uma integração entre os conceitos científicos. Revista de Ensino de Bioquímica, 12, 7-23.

29. Silveira, J. T., & Rocha, J. B. T. da. (2016). Produção científica sobre estratégias didáticas utilizadas no ensino de Bioquímica: Uma revisão sistemática. Revista de Ensino de Bioquímica, 14(1), 7-21.

30. Sousa, R. S. de, & Galiazzi, M. do C. (2018). O jogo da compreensão na análise textual discursiva em pesquisas na educação em ciências: Revisitando quebra-cabeças e mosaicos. Revista Ciência; Educação, 24(3), 799-814. https://doi.org/10.1590/1516-731320180030016

31. Sutton, J. (1996). Words, Science and Learning. Open University Press.

32. UEL/COPS-Coordenadoria de Processos seletivos. (n.d.). Universidade Estadual de Londrina, Coordenadoria de Processos seletivos [Web page]. Retrieved from https://www.cops.uel.br/

33. Vestibular Brasil Escola. (n.d.). Vestibular Brasil Escola [Web page]. Retrieved from https://vestibular.brasilescola.uol.com.br/

34. Victora, C. G., Knauth, D. R., & Hassen, M. de N. A. (2000). Pesquisa qualitativa em saúde: Uma introdução ao tema. Tomo editorial.

35. Zabala, A. (1998). Prática educativa: Como ensinar. ARTMED.