

Teaching and learning about enzymes at the undergraduate level: opportunities and challenges in biochemistry instruction

ABSTRACT

The teaching and learning of Biochemistry involve understanding the chemical processes that regulate essential biological functions. This study investigated teaching possibilities and conceptual learning gaps regarding enzymes in higher education through an analysis of previous studies and the administration of a questionnaire to undergraduate students in a Chemistry Teacher Education program and a Biological Sciences Teacher Education program. The results indicate difficulties, particularly in students' understanding of specific concepts such as enzyme functions, classifications, and interactions. High levels of absent, confused, and unknown understanding were identified. These findings directly affect the teaching process and pose a challenge for university instructors, as reflected in the limited number of studies exploring enzyme instruction, particularly at the higher education level. We concluded that the relationship between undergraduates' conceptual understanding difficulties and didactic possibilities warrants further exploration to promote reflection on pedagogical practices aimed at overcoming these difficulties and expanding the pedagogical repertoire of Biochemistry instructors.

KEYWORDS: Higher Education; Teacher Education; Learning Difficulties; Learning Problems; Chemistry.

Ensinar e aprender sobre enzimas na graduação: possibilidades e desafios na docência em bioquímica

RESUMO

O ensino e a aprendizagem de Bioquímica envolvem a compreensão de processos químicos que regulam funções biológicas essenciais. Neste estudo, foram investigadas as possibilidades de ensino e as lacunas conceituais de aprendizagem sobre enzimas no ensino superior, a partir da análise de estudos realizados anteriormente e da aplicação de um questionário com graduandos de um curso de Licenciatura em Química e de um curso de Licenciatura em Ciências Biológicas. Os resultados apontam dificuldades, sobretudo, na compreensão de conceitos específicos como, funções, classificações e interações enzimáticas, por parte dos estudantes. Altos índices de compreensões ausentes, confusas e desconhecidas foram verificados. Tais resultados impactam diretamente no processo de ensino e configuram-se como um desafio para a ação docente dos professores universitários, que se evidencia diante dos poucos trabalhos que abordam o ensino de enzimas, especialmente no ensino superior. Conclui-se que a articulação entre as dificuldades de compreensão conceitual dos graduandos e as possibilidades didáticas é um ponto a ser mais explorado, de modo a promover a reflexão sobre as práticas pedagógicas para a superação de tais dificuldades e a ampliação do repertório docente dos professores de Bioquímica.

PALAVRAS-CHAVE: Ensino Superior; Formação de Professores; Dificuldade de Aprendizagem; Problemas de Aprendizagem; Química.

Isaquel de Moura Ribeiro

Azevedo

isaquiel.azevedo@gmail.com

orcid.org/0000-0002-4208-0227

Universidade do Estado de Santa Catarina (UDESC), Joinville, Santa Catarina, Brasil

Brenno Ralf Maciel Oliveira

brenno.oliveira@udesc.br

orcid.org/0000-0002-4103-4739

Universidade do Estado de Santa Catarina (UDESC), Joinville, Santa Catarina, Brasil

INTRODUCTION

The teaching of biochemistry in undergraduate programs plays an important role in student development because it involves interdisciplinary knowledge (Almeida *et al.*, 2014; Balinha & Wyse, 2023) that contributes to students' understanding of biological processes at the molecular level. This includes chemical phenomena occurring in living organisms and the study of biomolecules such as proteins, carbohydrates, nucleic acids, and lipids, as well as their structures, functions, metabolic pathways, and regulatory mechanisms (Albuquerque *et al.*, 2012; Silveira & Rocha, 2016).

In this context, the topics covered in Biochemistry courses include, for example, the properties of water, buffer systems, amino acids, enzymes and enzyme kinetics, as well as vitamins and the metabolism of these biomolecules, providing a broad and integrated view of the field (Instituto Federal Catarinense, 2022; Universidade do Estado de Santa Catarina, 2017).

Among the various topics addressed in Biochemistry, the study of enzymes stands out because these molecules are essential for catalyzing biochemical reactions and maintaining vital processes. Enzymes are biomolecules that are either proteins or RNA molecules and that catalyze specific chemical reactions by reducing the activation energy required to convert substrates into products (Nelson & Cox, 2014). In addition, they are involved in nutrient degradation, energy conversion, and macromolecular synthesis. Enzymes are widely used in chemical engineering, food technology, and agriculture, with therapeutic and industrial applications, as well as applications in various scientific and technological fields (Nelson & Cox, 2014).

Thus, understanding enzyme structure, mechanism of action, and regulation is relevant to various fields, particularly the Biological Sciences and Chemistry, and extends beyond theoretical aspects to encompass biotechnological, industrial, and medical applications. Understanding enzyme kinetics requires knowledge of the concepts of enzymes and catalysis. Catalysts are substances that can increase the rate of a chemical reaction without being consumed. Enzymes, in turn, are proteins that belong to this group and regulate and accelerate reactions in living organisms (Seibert & Tracy, 2014).

In the context of Chemistry, the study of enzymes plays a fundamental role, as engineered enzymes offer a sustainable solution for the synthesis of complex organic molecules and enable the degradation of plastic waste and chemicals, thereby contributing directly to the development of new materials and biotechnological processes (Buller *et al.*, 2023).

In the field of Biological Sciences, understanding enzymes is fundamental both to understanding biological processes and to developing new strategies, such as EnzyACT, a deep learning strategy that combines graph techniques and protein embeddings to predict changes in enzymatic activity following mutations (Li *et al.*, 2024). Despite this importance, Xavier *et al.* (2023) discuss the difficulties or aversion that undergraduate students in Biological Sciences often experience toward courses in the exact sciences, which are partly related to the teaching methodologies and strategies used by instructor.

Enzyme kinetics is an essential component of the curriculum in undergraduate programs in Chemistry and Biological Sciences, particularly for students interested

in research areas (Her *et al.*, 2015). Incorporating such approaches can contribute to a broad and integrated understanding of the topics addressed, stimulating critical thinking and the ability to make connections across different disciplines.

Despite this importance, many students hold misconceptions about the nature of enzyme-substrate interactions, maintain naive views of the active site, and lack an understanding of energetically oriented interactions (Linenberger & Bretz, 2015). Consequently, misconceptions arise regarding how enzymes and substrates interact during an enzymatic reaction, leading to a simplified or incorrect understanding of this process. This can hinder students' learning of these concepts in Biochemistry and cause conceptual distortions that interfere with learning progression, highlighting the need for reflection on teaching practices and, consequently, on teacher education. Thus, identifying and documenting students' difficulties in learning chemical concepts can serve as an important strategy for planning and organizing activities carried out with students (Marani *et al.*, 2017).

Students frequently perceive Biochemistry as a highly complex discipline with content that is difficult to grasp, primarily due to the wide range of chemical structures and reactions that are often presented in an abstract manner and disconnected from professional practice (Albuquerque *et al.*, 2012; Alcantara *et al.*, 2022; Andrade *et al.*, 2017; Silveira & Rocha, 2016). This difficulty intensifies when the discipline is taught in the early semesters of undergraduate programs, a period when students do not yet have a solid foundation for relating theoretical concepts to concrete applications in their future professional practice. Similarly, teaching this content can present challenges, especially when it is approached in a purely theoretical manner and disconnected from practice.

Teaching and learning become challenging when they involve abstract concepts, which can compromise students' understanding in higher education (Albrecht & Oliveira, 2020; Galieta, 2020; Cunha, 2011). Other factors, such as "difficulty in completing courses in specific areas" and "lack of interest" (Silva & Figueiredo, 2018), corroborate discussions of the obstacles encountered in this context, highlighting the challenges experienced by both faculty and students and the complexity of the teaching and learning process.

Many of the difficulties related to content in higher education originate in high school (Amaral *et al.*, 2024). One of the main learning difficulties in biochemistry is associated with gaps in students' high school education, highlighting persistent challenges in their comprehension and learning (Andrade *et al.*, 2017). This phenomenon may be related to gaps in foundational education, unengaging teaching methodologies, or the increasing complexity of content addressed at more advanced levels of education.

A study of 622 higher education students enrolled in programs that share a biochemistry course, including Chemistry and Biological Sciences, found that, among the most complex topics in biochemistry, biosignaling (33.3%), enzymes (32.5%), and metabolic integration (27.5%) were among the most challenging for students to understand (Andrade *et al.*, 2017).

Given changes in students' profiles, there is a clear need to transform teaching strategies (Albrecht & Oliveira, 2020; Cunha, 2011). In this context, it is essential to develop and incorporate new strategies that promote the integration of

knowledge, taking into account the evidence and perspectives emerging from recent research.

Against this backdrop, the present study was designed to identify didactic possibilities related to the topic of enzymes and to characterize some challenges associated with students' learning difficulties in a biochemistry course offered within a Chemistry teacher education program and a Biological Sciences teacher education program at a public university in Santa Catarina, Brazil.

METHODOLOGICAL APPROACH

This study is a qualitative investigation focused on understanding subjective aspects of a specific context involving teaching and learning, which cannot be reduced to mere quantification and/or the operationalization of variables (Minayo, 2009). The study represents a segment of a master's research project and comprises two fundamental components: the characterization of studies exploring didactic strategies for teaching Biochemistry concepts and the administration of a questionnaire to identify conceptual difficulties faced by undergraduate students in learning these concepts.

The literature search was conducted through the CAPES Journal Portal (Coordination for the Improvement of Higher Education Personnel) to identify articles exploring strategies and approaches to teaching Biochemistry, both from a general perspective and specifically in relation to enzymes. The following search terms were used: "Enzimas" AND "Ensino" OR "Ensino de Química" OR "Ensino de Bioquímica" ("Enzymes" AND "Teaching" OR "Chemistry Teaching" OR "Biochemistry Teaching"). Selection was based on previously established inclusion criteria: the study had to be a scientific article, published between 2004 and 2024, peer-reviewed, and focused on teaching and learning in Chemistry and Biochemistry within the Brazilian context.

Initially, titles, abstracts, and keywords were evaluated to identify articles that met the established criteria. Subsequently, the preselected articles were read in full to identify the main aspects of each text. To address the objectives of the study, we sought to identify knowledge gaps, understood as aspects of the topic that had not yet been sufficiently explored. For the analysis, the articles were organized by authorship, title, year of publication, and focus of the study.

In the second stage, a questionnaire was developed, validated, and administered to 22 students from two classes in teacher education programs, one in Chemistry (8 students) and the other in Biological Sciences (14 students), to assess their knowledge of enzymes and identify their conceptual difficulties. The questionnaire was organized into three sections, as presented in Tables 1, 2, and 3. Notably, all respondents had already completed the Biochemistry course in their respective undergraduate programs.

Table 1

Diagnostic Questionnaire (DQ): Personal Characterization and Perceptions

Questions: Part I
1. Name
2. Age
3. Biological sex
4. In which school system did you complete high school? () State; () Federal; () Private.
5. How long ago did you complete high school? () 1 year or less; () 2 years; () 3 years; () 4 years; () 5 years or more.
6. How long ago did you take the Biochemistry course in your undergraduate program?
7. Identify Biology and Chemistry concepts that were important for your learning in the Biochemistry course during your undergraduate studies.
8. Which topics did you find most challenging when learning about Biochemistry?
9. What are the main difficulties you faced when studying enzymes?

Source: Prepared by the authors (2025).

Table 2

Diagnostic Questionnaire (DQ): Conceptual Aspects

Questions – Part II
10. What is a substrate?
11. What are enzymes?
12. Explain the relationship between enzyme action and activation energy in a chemical reaction.
13. What is the function of an enzyme's active site?
14. What are the classifications (names of the classes) of enzymes?
15. What is the optimal pH for an enzyme?
16. How do temperature and pH affect enzyme activity?
17. How are amino acids classified based on their R groups (or side chains)?

Source: Prepared by the authors (2025).

Table 3
Diagnostic Questionnaire (DQ): Applied Contextual Aspects

Questions – Part III
18. Describe the biochemical processes that lead to the browning of a banana, even when it is stored at low temperatures.
19. When a wound is cleaned with hydrogen peroxide (H ₂ O ₂), bubbling occurs at the site of the wound because the cells in the area contain peroxisomes. Explain this phenomenon and its relationship to enzymes.
20. Pepsin is an enzyme present in gastric juice, which is produced by the glandular cells of the stomach. Explain how pepsin acts during protein digestion and relate its activity to changes in pH in the presence of gastric juice.
21. During a high fever, the human body experiences a significant increase in temperature, and in isolated cases, body temperature can exceed normal levels, reaching 42 °C. This condition can affect proteins in the body. Explain how this condition can influence protein function.
22. DNA replication in eukaryotic cells is a highly coordinated process that requires the action of multiple enzymes and proteins to ensure accurate and complete replication of the genome. Regarding the enzymes involved in DNA replication, describe the respective functions of DNA topoisomerase, DNA polymerase, DNA helicase, DNA ligase, and DNA primase.
23. Describe the functions of enzymes in the production of ethanol from biomass, highlighting their role in obtaining ethanol as a biofuel.

Source: Prepared by the authors (2025).

The questionnaire was administered in person via Google Forms, in accordance with the ethical procedures approved for this study (CAAE 61121822.5.0000.0118). Participants were provided with details about the research and signed an Informed Consent Form. To ensure the privacy and protection of the individuals involved, participant names were replaced with pseudonyms.

The data analysis and processing were based on Content Analysis (Bardin, 2016), organized into three main stages: I) Pre-analysis, involving the “floating reading” of all the material; the “selection of the material corpus” based on inclusion and exclusion criteria for the dialogues or responses analyzed; and the “formulation of hypotheses” for possible questions (Bardin, 2016; Valle & Ferreira, 2024); II) Exploration of the material, involving the “coding” of questionnaire or dialogue responses into units of registration with meaning for the analysis, followed by the “categorization” of these units (Bardin, 2016; Valle & Ferreira, 2024); and III) Processing and interpretation of results, comprising the “analysis of categorized data” and the “inference of patterns” based on the results, seeking to relate the identified categories to the questions initially formulated and, finally, the “final interpretation” of the results within the context of the study, attributing meaning to them (Bardin, 2016; Valle & Ferreira, 2024). Based on this Content Analysis framework, NVivo 14® was used for data categorization and qualitative analysis, using the coding labels presented in Table 4.

Finally, the data were organized and quantified in Microsoft Excel® spreadsheets, allowing for a structured analysis and categorization through the quantification of the identified difficulties, with the aim of qualitatively interpreting the results and identifying the most significant aspects.

Table 4
Markers Used for Coding Responses

Marker	Código	Definition
Full Conceptual Understanding	CCT	Responses that are completely correct.
Incomplete Conceptual Understanding	CCI	Responses that are incomplete and lack one or more central aspects.
Confused Conceptual Understanding	CCC	Responses that show confusion between concepts or contain contradictions.
Absent Conceptual Understanding	CCA	Responses that are completely incorrect and/or out of context.
Unknown Conceptual Understanding	CCD	Responses in which participants stated, "I don't know," "I don't remember," or "We haven't studied this."
Confused, Absent, and Unknown Conceptual Understanding	ACD	Grouping of the CCC, CCA, and CCD markers to synthesize the final data.

Source: Prepared by the authors (2025).

RESULTS AND DISCUSSION

As a result of the characterization of studies on the teaching of Biochemistry, 15 articles were identified that met the inclusion criteria defined in the methodology of this study. The articles were organized according to year of publication, author-ship, title, journal, educational level addressed in the discussion, and type of instructional strategy explored. Table 5 presents the main aspects of the articles considered eligible.

Table 5
Studies Discussing the Teaching of Biochemistry

Year	Authors	Article Title*	Journal
2022	Bevilaqua <i>et al.</i>	Bioluminescent demonstration of ATP using recombinant firefly luciferase in bioenergetics practical classes	R1-EM
2022	Monteiro <i>et al.</i>	Inquiry-based teaching in Chemistry classes: Building argumentation through the problem "Why do bananas turn brown?"	R2-EM
2021	Gonçalves.	Experiencing Biology: A proposal for a practical class on catalase enzymatic activity	R3-EM
2021	Mendonça & Fontana.	Variation in vitamin C concentration in orange juices stored under different light and temperature conditions	R4-EM
2021	Freire <i>et al.</i>	Analysis of creatine kinase enzyme activity and the CK-MB isoenzyme: Simulation for remote teaching	R1-EM
2020	Martins <i>et al.</i>	The role of computational models and analogies in learning the drug-enzyme interaction process in modeling-based teaching	R5-EM
2020	Pastore & Pirovani.	Shall we learn about enzyme action?	R6-EM
2019a	Almeida & Bossolani-Kiill.	Three-dimensional modeling: Reflections of future Chemistry teachers on the teaching and learning of enzyme-substrate interaction	R1-EM
2019b	Almeida & Bossolani-Kiill.	Construction of 3D-printed models as a strategy for learning the concept of enzyme-substrate interaction	R7-EM
2015	Oliveira <i>et al.</i>	A construction game for collaborative learning of glycolysis and gluconeogenesis	R1-EM
2014	Almeida <i>et al.</i>	From enzymes to sensory analysis: Report of an interdisciplinary practical class	R1-EM
2014	Clerici <i>et al.</i>	Enzymatic browning: A practical class	R1-ESM
2013	Tauceda <i>et al.</i>	The study of the cell through enzyme-related problem situations: A proposal for meaningful learning within the conceptual fields framework with high school students	R8-EM
2011	Pinheiro & Pompilho.	Teaching enzymes: A low-cost experimental approach	R1-EM
2006	Clerici <i>et al.</i>	Carbohydrate digestion using commercial digestive enzymes: A practical class	R1-EM

Legend: EM = Higher Education; ES = Secondary Education; ESM = Higher and Secondary Education. R1 = Journal of Biochemistry Education; R2 = Revista Insignare Scientia (RIS); R3 = Revista Brasileira do Ensino Médio; R4 = Revista Thema; R5 = Re-vista Brasileira de Pesquisa em Educação em Ciências; R6 = Health and Biosciences; R7 = Investigações em Ensino de Ciências; R8 = Enseñanza de las Ciencias (Online). *Titles were translated into English.

Source: Prepared by the authors (2025).

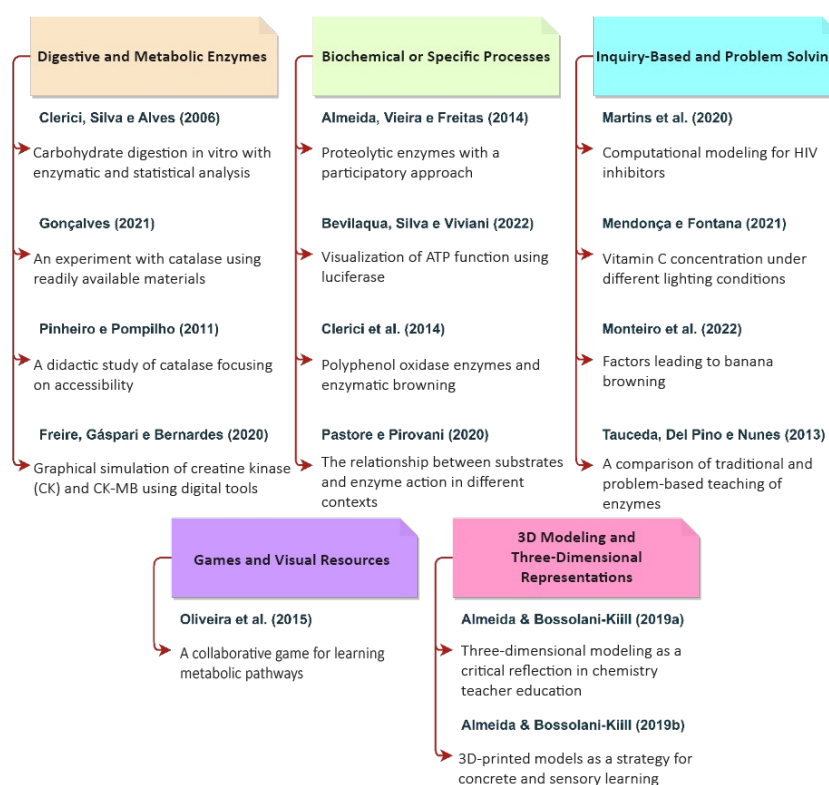
Some of the identified articles adopt an approach centered on experimentation, based on the general premise of providing situations that foster inquiry-based practices related to the study of enzymes (Almeida *et al.*, 2014; Clerici *et al.*, 2006; Bevilaqua *et al.*, 2022; Gonçalves, 2021; Clerici *et al.*, 2014; Monteiro *et al.*, 2022; Pinheiro & Pompilho, 2011). Several studies criticize the traditional teaching

model, which remains centered on the teacher. The inquiry-based approaches identified in these studies extend beyond the classroom, encouraging students to construct more consolidated knowledge that is not limited to the academic environment but can also be applied in situations beyond this context.

Games constitute an alternative teaching strategy that can contribute to knowledge acquisition and foster greater student interest in and acceptance of the teaching and learning process (Alcantara *et al.*, 2022). The data indicate a trend toward diversifying teaching methodologies and strategies (Figure 1) through more participatory and inquiry-based practices. These practices incorporate technological resources and strategies such as experimentation and gamification, which may enhance student learning and stimulate the development of critical and analytical skills.

Figure 1

Focus of the articles



Source: Prepared by the authors (2025).

Some studies present teaching approaches, such as experiments, simulations, and inquiry-based activities (Almeida *et al.*, 2014; Pastore & Pirovani, 2020; Monteiro *et al.*, 2022), that encourage students to actively participate in the learning process. One study, for example, proposes an experiment using proteolytic enzymes to help undergraduates better understand biochemical reactions, highlighting the importance of a teaching approach that fosters student participation in the learning process (Almeida *et al.*, 2014).

Several studies highlight that experimental activities (Bevilaqua *et al.*, 2022; Clerici *et al.*, 2014; Clerici *et al.*, 2006; Gonçalves, 2021; Mendonça & Fontana,

2021; Pinheiro & Pompilho, 2011), including low-cost approaches (Gonçalves, 2021; Pinheiro & Pompilho, 2011), constitute valuable resources for bridging theoretical concepts and concrete situations. These experiments not only allow students to observe evidence related to biochemical processes but also promote a deeper understanding of the topics addressed.

Other studies have explored the integration of digital tools and visual resources, such as Paint and PowerPoint, for simulating experiments (Almeida & Bossolani-Kiill, 2019a; Almeida & Bossolani-Kiill, 2019b; Freire *et al.*, 2021; Martins *et al.*, 2020). These studies suggest that the use of technology can facilitate the understanding of complex processes, such as enzymatic mechanisms, through dynamic visual representations.

Another approach identified in one of the studies is gamification, used as a pedagogical tool through games aimed, for example, at teaching metabolic pathways. This approach offers an engaging and collaborative alternative. Gamification can increase undergraduate students' engagement with Biochemistry, while also fostering collaborative learning and making the visualization of concepts more accessible (Oliveira *et al.*, 2015).

Several studies propose innovations while also critiquing the traditional teaching model. This highlights the need to move beyond teacher-centered pedagogical practices and expand initiatives that promote inquiry and experimentation. Solving complex problems can foster greater student engagement and facilitate conceptual understanding (Tauceda *et al.*, 2013). Many of these inquiry-based approaches emphasize the integration of different areas of knowledge. For example, in an experiment exploring vitamin C concentration in orange juice, concepts from Chemistry and Biochemistry can be taught in a contextualized and interdisciplinary manner (Mendonça & Fontana, 2021).

Experimentation constitutes an important component of the teaching and learning process (Galieta, 2020), as it can contribute to knowledge construction by bringing students closer to the phenomena under study and encouraging their active participation in educational activities. Among the pedagogical possibilities within the educational context, practical-experimental activities allow teachers and students to integrate theory and practice (Galieta, 2020), while revisiting previously addressed knowledge and analyzing evidence that contributes to the understanding and validation of scientific concepts.

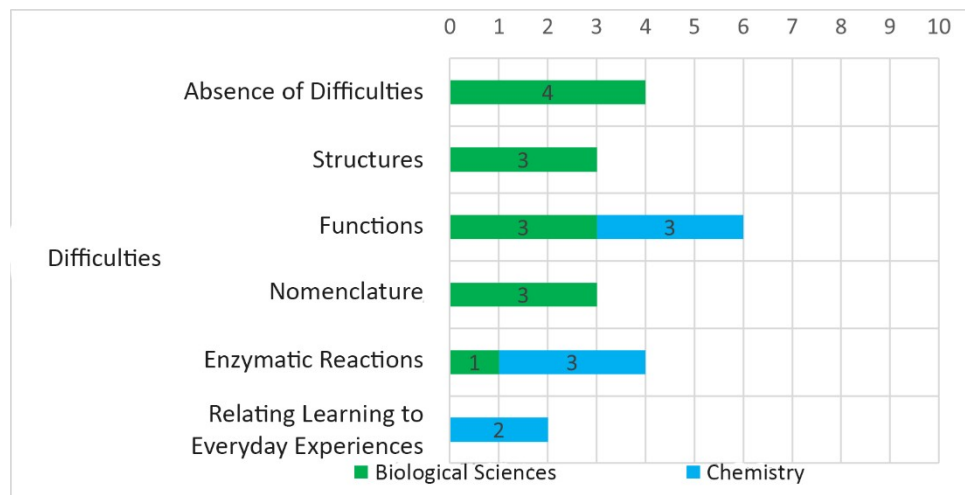
Critical reflection on the pedagogical approaches employed in teaching complex topics, such as enzymes, is therefore essential. Despite advances in the field, studies that analyze student learning and explore teaching perspectives capable of fostering greater undergraduate engagement remain relatively scarce, particularly in the context of higher education. This gap points to the need for a deeper analysis of how undergraduate students actually learn about enzymes in Biochemistry courses, with the aim of understanding how meanings are constructed throughout this process and identifying potential conceptual difficulties or gaps in their education. Such discussions can inform pedagogical practices that are aligned with the needs of undergraduate students.

From this perspective, the students' responses to the questionnaire administered in this study indicated that enzyme functions were the primary difficulty in

both programs, with three mentions in the Chemistry program, as shown in Figure 2.

Figure 2

Primary difficulties of undergraduate students related to enzymes



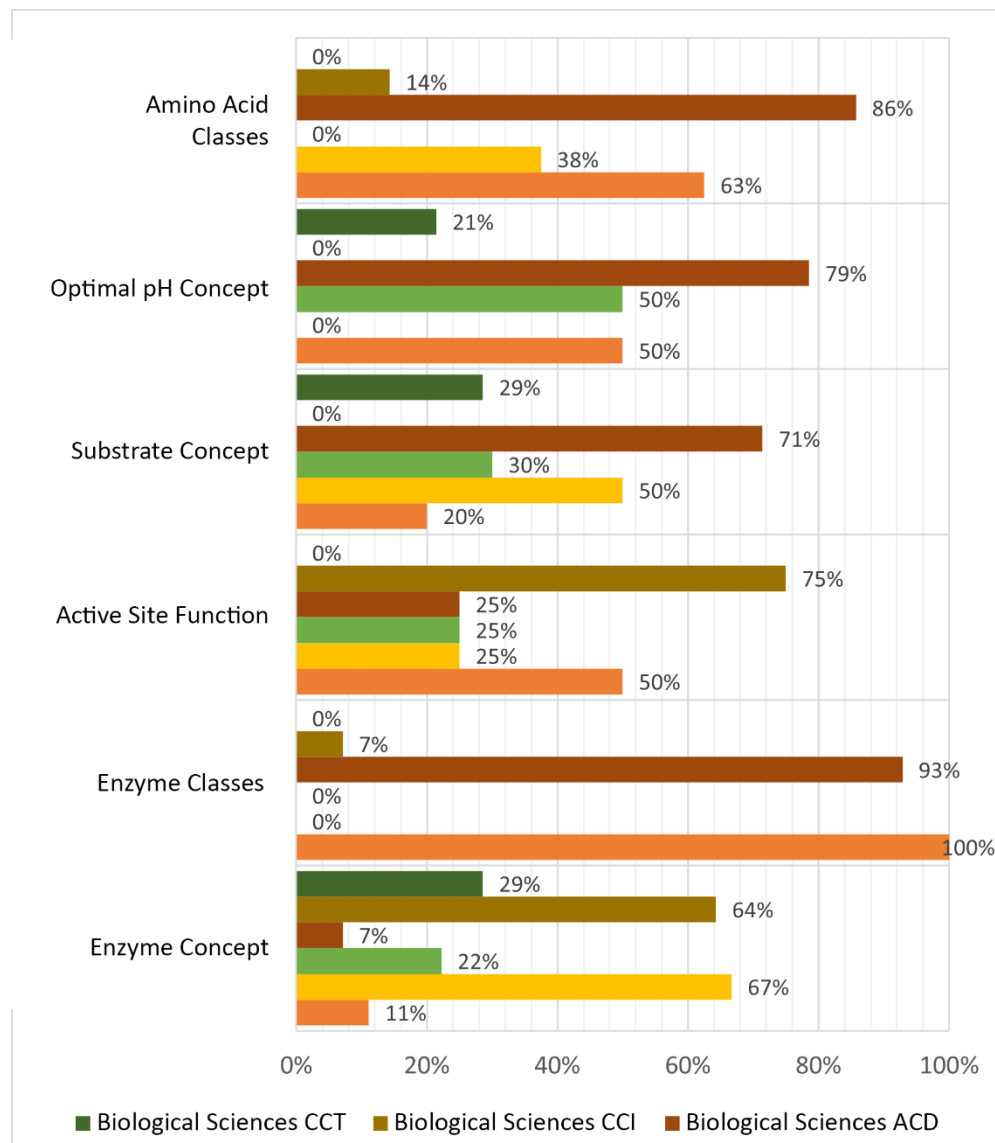
Source: Prepared by the authors (2025).

Some students reported having encountered no difficulties when studying enzymes in the Biochemistry course (absence of difficulties), while the remaining students mentioned, with equal frequency, that their main difficulties involved aspects related to Structures, the Nomenclature of Enzymatic Compounds, Enzymatic Reactions, and the ability to Relate Learning to everyday experiences (two mentions each). In addition, other topics considered challenging were mentioned less frequently, including Catalysis and Enzyme Inhibition, Differentiating Enzymes, Structures, Chain Lengths, Cycles, Current Difficulties, and Reactions.

Regarding the conceptual and applied questions, it is possible to identify the topics in which difficulties are concentrated and conduct a detailed analysis of student performance. Analysis of the distribution of these categories across different topics indicates that most undergraduates face considerable difficulties with many key concepts (Figure 3) and in applying these concepts to real-world situations (Figure 4).

Figure 3

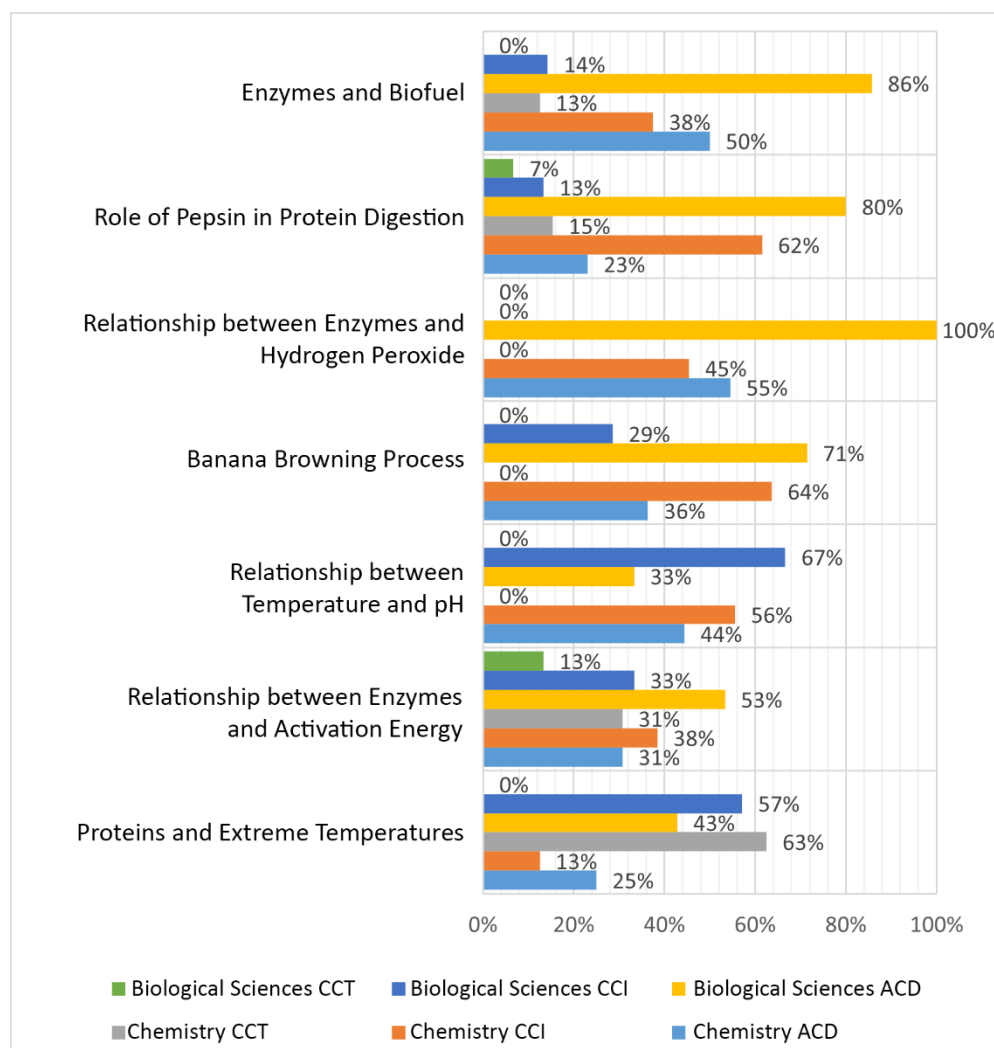
Percentage Classification by Frequency in Conceptual Questions



Source: Prepared by the authors (2025).

Figure 4

Percentage Classification by Frequency in Applied Questions



Source: Prepared by the authors (2025).

Responses classified as CCT occurred among a minority of students, indicating a low frequency of responses consistent with Full Conceptual Understanding across the topics assessed. Only a few topics in the Chemistry program, such as “Substrate,” “Optimal pH,” and “Proteins and Temperatures,” yielded more than two responses classified as CCT. In the Biological Sciences program, “Substrate” and “Enzyme” were the topics with the highest number of CCT responses, with four undergraduate students in each case. Nevertheless, the distribution of the remaining responses indicates the presence of conceptual difficulties in these and other topics. Moreover, some concepts, such as “Function of the Active Site,” “Classification of Enzymes,” and “Relationship between Enzymes and Peroxides,” did not yield any responses classified as CCT, indicating an absence of responses consistent with Full Conceptual Understanding in these topics.

CCI was the most frequent category among the responses from undergraduate students in the Chemistry program, indicating that many students demonstrate some degree of understanding but still have conceptual gaps. This pattern is

evident in topics such as “Substrate,” “Enzyme,” and “Pepsin’s Role.” These data suggest that, although many students have a general understanding of the terms, their understanding of the assessed concepts remains partial and marked by gaps. In the Biological Sciences program, the frequency of responses classified as CCI indicates topics in which students demonstrate partial understanding, but not sufficient to explain the concepts in depth. Topics such as “Function of the Active Site,” “Relationship between Temperature and pH,” and the concept of “Enzyme” were frequently observed in this category. This indicates that, despite some familiarity with these concepts, there remains a need to deepen students’ understanding of them.

In the Chemistry program, the highest frequencies of difficulties were observed in the ACD category. Some topics, such as “Enzyme Classification,” “Amino Acid Classification,” and “Relationship between Enzymes and Peroxide,” showed a high frequency of responses classified as ACD, indicating confused, absent, or unknown conceptual understanding. These results indicate that students’ main difficulties are related to the classification and understanding of more complex concepts, such as the relationships between enzymes and other substances. Understanding enzyme classifications, as observed in the topics “Enzyme Classification” and “Amino Acid Classification,” is challenging for undergraduates, as no responses in these topics were classified as CCT. In addition, enzymatic processes, such as “Relationship between Enzymes and Peroxide” and “Pepsin Relationship,” also prove challenging. These areas show a high proportion of responses in the ACD category, suggesting significant difficulties in understanding the concepts assessed.

For the Biological Sciences program, the high frequency of ACD responses highlights the topics in which undergraduates experience the greatest difficulties. Among these topics, “Relationship between Enzymes and Peroxides,” in which all undergraduates demonstrated confusion or lack of knowledge, and “Enzyme Classification,” with 13 responses classified as ACD, stand out. Other topics, such as “Optimal pH” and the “Browning Process,” also presented significant difficulties. These results suggest that undergraduates have considerable difficulty understanding both enzyme function and classification, as well as enzymatic processes influenced by variables such as pH and temperature. Some specific topics warrant particular attention because of the predominance of responses in the ACD category. The topics “Enzymes and Biofuels” and “Pepsin and Amino Acid Classification” deserve special attention, as they concentrate responses classified as ACD. These results indicate greater difficulties among students in these topics. One possible explanation, which warrants further investigation, is that students perceive these topics as more abstract or less familiar. This reinforces the relevance of investigating differentiated teaching strategies, such as experimental activities or the use of multimedia resources that illustrate the biological interactions and functions involved.

The results highlight difficulties in understanding fundamental concepts related to enzymes, including their functions, classifications, and interactions, as well as in applying these concepts to the situations assessed. The predominance of responses classified as ACD and CCI indicates that a significant proportion of undergraduates demonstrated absent, confused, unknown, or incomplete understanding of the topics investigated. Furthermore, the low frequency of responses classified as Total Conceptual Understanding (CCT), with averages of 19% in

Chemistry and 8% in Biological Sciences, reinforces the presence of conceptual difficulties in both groups. Differences between the programs were also observed, with a higher frequency of ACD responses among Biological Sciences students across several topics. These differences point to the relevance of investigating, in future studies, possible relationships with students' educational experiences and with the ways in which these concepts are addressed in their respective programs.

In view of these results, it is important to examine the relationship between the difficulties identified and the teaching strategies employed in higher education programs, as well as to reflect on university teacher education, with the aim of recognizing students' learning difficulties as a starting point for planning and implementing classroom activities.

FINAL REMARKS

This study highlighted, in the literature, the use of experimentation, technological resources, and gamification as potential alternatives for making the teaching of enzymes more engaging and fostering learning.

The study also identified difficulties among higher education students in learning enzyme-related concepts, highlighting challenges that directly affect knowledge acquisition and instructional practice. High rates of Confused, Absent, and Unknown Conceptual Understanding (CAU) were observed, with averages of 43% in Chemistry and 64% in Biological Sciences, as well as rates of Incomplete Conceptual Understanding (CCI), averaging 38% and 29%, respectively.

The implications of these findings point to the need for Biochemistry instruction grounded in practices that promote inquiry and collaborative learning, both to stimulate students' interest and engagement in class and to help address learning difficulties.

In this context, critical reflection on university instructor preparation and on the incorporation of the instructional strategies and pedagogical possibilities reported in the literature into their formative processes is warranted. This includes investigating the extent to which these strategies and pedagogical possibilities have been incorporated into university instructor preparation, whether through continuing education or graduate-level training. Master's and doctoral education could contribute more effectively to preparing these instructors for teaching, considering the specificities of the content and the particular context of teaching and learning in higher education. In view of the results presented in this study, these reflections point to the need to examine the adequacy of instructor preparation in relation to these challenges, as well as to consider students' learning difficulties as a starting point for organizing instructional practice.

ACKNOWLEDGMENTS

To the Foundation for Research and Innovation Support of the State of Santa Catarina (FAPESC) for funding this study.

REFERENCES

- Albrecht, M. P. S.; Oliveira, F. E. de. (2020). Jogo eletrônico para o ensino de Biologia Celular. *ACTIO, Curitiba*, 5(3), 1-18.
<http://dx.doi.org/10.3895/actio.v5n3.12493>
- Albuquerque, M. A. C., Amorim, Â. H. C., Rocha, J. R. C. F., Silveira, L. M. F. G., & Neri, D. F. M. (2012). Bioquímica como sinônimo de ensino, pesquisa e extensão: Um relato de experiência. *Revista Brasileira de Educação Médica*, 36(1), 137–142. <https://doi.org/10.1590/S0100-55022012000100019>
- Alcantara, S. S., Gomes, P. H. B., Ruiz, C. R., & Martins, A. P. (2022). BioDomínio: Uma maneira divertida de trabalhar o conteúdo de bioquímica. *Revista de Ensino de Bioquímica*, 20(1), 78–89. <https://doi.org/10.16923/reb.v20i1.975>
- Almeida, D. J., Vieira, R. L. D., & Freitas, G. B. L. (2014). Das enzimas à análise sensorial: Relato de aula prática interdisciplinar. *Revista de Ensino de Bioquímica*, 12(2), 55–70.
<https://www.bioquimica.org.br/index.php/REB/article/view/322>
- Almeida, J. F., & Kiill, K. B. (2019a). Modelagem tridimensional: Reflexões de futuros professores de Química para o ensino e aprendizagem da interação enzima-substrato. *Investigações em Ensino de Ciências*, 24(3), 282–304.
<https://doi.org/10.22600/1518-8795.ienci2019v24n3p282>
- Almeida, J. F., & Kiill, K. B. (2019b). Construção de modelos 3D impressos como estratégia para a aprendizagem do conceito de interação enzima-substrato. *Revista de Ensino de Bioquímica*, 17, 74–93.
<https://doi.org/10.16923/reb.v17i0.858>
- Amaral, A. M. F., Correa, R. M. S., Belo, T. O., Coelho, H. J. P., Costa, C. V. C., Macedo, D. B., Souza, J. M. M., & Rodrigues, M. D. N. (2024). Path Glykos: Uma ferramenta lúdica para o ensino de bioquímica. *Revista de Educação, Ciências e Tecnologia do IFAM*, 18(1).
<https://igapo.ifam.edu.br/index.php/igapo/article/view/325>
- Andrade, R. S. B., Silva, A. F. S., & Zierer, M. S. (2017). Avaliação das dificuldades de aprendizado em bioquímica dos discentes da Universidade Federal do Piauí. *Journal of Biochemistry Education*.
<https://www.bioquimica.org.br/index.php/REB/article/view/690>
- Balinha, D. M., & Wyse, A. T. S. (2023). ATraPalhados revisando bioquímica: Foco na respiração celular. *Revista de Ensino de Bioquímica*, 21(1), 17–33.
<https://doi.org/10.16923/reb.v21i1.1038>
- Bardin, L. (2016). *Análise de conteúdo* (1ª ed.). Edições 70.

- Bevilaqua, V. R., Silva, J. R., & Viviani, V. R. (2022). Demonstração bioluminescente de ATP com luciferase recombinante de vagalume (*Amydetes vivianii*) em aulas práticas de bioenergética. *Revista de Ensino de Bioquímica*, 20(2), 209–228. <https://doi.org/10.16923/reb.v20i2.1006>
- Buller, R., Lutz, S., Kazlauskas, R. J., Snajdrova, R., Moore, J. C., & Bornscheuer, U. T. (2023). From nature to industry: Harnessing enzymes for biocatalysis. *Science*, 382(6673). <https://doi.org/10.1126/science.adh8615>
- Clerici, M. T. P. S., Sebastião, R. H., Oliveira, L. C., Santos, M. S., Moraes, A. L. L., & Clareto, S. S. (2014). Escurecimento enzimático: Uma aula prática. *Revista de Ensino de Bioquímica*, 12(2), 71–90. <https://www.bioquimica.org.br/index.php/REB/article/view/275>
- Clerici, M. T. P. S., Silva, R. S., & Alves, A. A. (2006). Digestão de carboidratos usando digestivos enzimáticos comerciais: Uma aula prática. *Journal of Biochemistry Education*, 4(1), 8. <https://www.bioquimica.org.br/index.php/REB/article/view/19>
- Cunha, K. M. C. (2011). *O ensino e a aprendizagem significativa da célula no contexto da disciplina Biologia do primeiro ano do ensino médio em uma escola pública do Rio de Janeiro*. 2011. Dissertação (Mestrado em Biociências e Saúde) – Instituto Oswaldo Cruz, Rio de Janeiro.
- Freire, B. F., Gáspari, P. F., & Bernardes, C. F. (2021). Análise da atividade da enzima creatina quinase e da isoenzima CK-MB: Simulação para ensino remoto. *Revista de Ensino de Bioquímica*, 18(2), 56–61. <https://www.bioquimica.org.br/index.php/REB/article/view/950>
- Galieta, T. (2020). Contribuições de atividades prático-experimentais para a formação de professores: reflexões a partir de um projeto de iniciação à docência em biologia. *ACTIO*, 5(2), 1-23. <http://dx.doi.org/10.3895/actio.v5n2.11286>
- Gonçalves, T. M. (2021). Experimentando a biologia: Uma proposta de aula prática sobre a atividade enzimática da catalase. *Revista Brasileira do Ensino Médio*, 4, 92–100. <https://doi.org/10.5281/zenodo.5119774>
- Her, C., Alonzo, A. P., Vang, J. Y., Torres, E., & Krishnan, V. V. (2015). Real-time enzyme kinetics by quantitative NMR spectroscopy and determination of the Michaelis–Menten constant using the Lambert-W function. *Journal of Chemical Education*, 92(11), 1943–1948.
- Instituto Federal Catarinense. (2022). *Projeto pedagógico do curso superior de licenciatura em química*. IFC.
- Li, G., Zhang, N., Dai, X., & Fan, L. (2024). EnzyACT: A novel deep learning method to predict the impacts of single and multiple mutations on enzyme activity. *Journal of Chemical Information and Modeling*, 64(15), 5912–5921. <https://doi.org/10.1021/acs.jcim.4c00920>

- Linenberger, K. J., & Bretz, S. L. (2015). Biochemistry students' ideas about how an enzyme interacts with a substrate. *Biochemistry and Molecular Biology Education*, 43(4), 213–222. <https://doi.org/10.1002/bmb.20868>
- Marani, P. F.; Oliveira, T. A. L. de.; Sá, M. B. Z. (2017). Concepções sobre Cinética Química: a influência da temperatura e da superfície de contato. *ACTIO*, 2(1), 321-341. <http://dx.doi.org/10.3895/actio.v2n1.6777>
- Martins, D., Mozzer, N. B., Oliveira, T. M. A., & Caetano, M. S. (2020). O papel dos modelos computacionais e das analogias na aprendizagem do processo de interação fármaco-enzima no ensino fundamentado em modelagem. *Revista Brasileira de Pesquisa em Educação em Ciências*, 20, 823–854. <https://doi.org/10.28976/1984-2686rbpec2020u823854>
- Mendonça, J. K. A., & Fontana, T. C. (2021). Variação da concentração de vitamina C em sucos de laranja armazenados sob diferentes condições de luminosidade e temperatura. *Revista Thema*, 19(1), 95–106. <https://doi.org/10.15536/thema.V19.2021.95-106.1459>
- Minayo, M. C. S. (2009). O desafio do conhecimento: pesquisa qualitativa em saúde. São Paulo: Hucitec.
- Monteiro, E. P., Libório, R. M., Teixeira, Y. B. S., & Nascimento, M. S. (2022). Ensino por investigação em aulas de química: Construindo a argumentação através da problemática “Por que as bananas escurecem”. *Revista Insignare Scientia*, 5(1), 506–524. <https://doi.org/10.36661/2595-4520.2022v5n1.12450>
- Nelson, D. L., & Cox, M. M. (2014). *Princípios de bioquímica de Lehninger* (6ª ed.). Artmed.
- Oliveira, F. S., Lacerda, C. D., Oliveira, P. S., Coelho, A. A., & Bianconi, M. L. (2015). Um jogo de construção para o aprendizado colaborativo de glicólise e gliconeogênese. *Revista de Ensino de Bioquímica*, 13(1), 45–57. <https://doi.org/10.16923/reb.v13i1.535>
- Pastore, N. R., & Pirovani, J. C. M. (2020). Vamos aprender sobre a ação das enzimas? *Health and Biosciences*, 1(3), 55–67.
- Pinheiro, W. A., & Pompilho, W. M. (2011). O ensino de enzimas: Uma abordagem experimental de baixo custo. *Revista de Ensino de Bioquímica*, 9(1), 1–8.
- Seibert, E., & Tracy, T. S. (2014). Fundamentals of enzyme kinetics. In S. Nagar, U. Argikar, & D. Tweedie (Eds.), *Enzyme kinetics in drug metabolism: Fundamentals and applications*. Humana Press. https://doi.org/10.1007/978-1-62703-758-7_2
- Silva, K. N. da; Figueiredo, M. C. (2018). Curso de licenciatura em química: motivações para a evasão discente. *ACTIO*, 3(2), 237-254.

Silveira, J. T., & Rocha, J. B. T. (2016). Produção científica sobre estratégias didáticas utilizadas no ensino de bioquímica: Uma revisão sistemática. *Revista de Ensino de Bioquímica*, 14(3), 7–21.

Tauceda, K. C., Del Pino, J. C., & Nunes, V. M. (2013). O estudo da célula através de situações-problema relacionados a enzima: Uma proposta para aprendizagem significativa no referencial dos campos conceituais com alunos do ensino médio. *Enseñanza de las Ciencias* (Número extra), 754–758. <https://raco.cat/index.php/Ensenanza/article/view/306197>

Universidade do Estado de Santa Catarina. (2017). *Projeto pedagógico do curso de licenciatura em ciências biológicas*. UDESC.

Valle, P. R. D., & Ferreira, J. L. (2024). Content analysis in the perspective of Bardin: Contributions and limitations for qualitative research in education. *SciELO Preprints*. <https://doi.org/10.35699/edur.v41i41.49377>

Xavier, T. K. D.; Tavares, M. G.; Bontempo, G. C. (2023). Avaliação do desempenho dos graduandos de ciências biológicas nas disciplinas das ciências exatas: uma visão para além das fórmulas. *ACTIO*, 8(2), 1-21. <http://dx.doi.org/10.3895/actio.v8n2.16873>

Received: Mar. 21, 2026
Approved: Aug. 20, 2026
DOI: <https://doi.org/10.3895/actio.v11n3.21610>

How to cite:

Azevedo, I. de M. R. & Oliveira, B. R. M. (2026). Teaching and learning enzymes in undergraduate education: possibilities and challenges of teaching in biochemistry. *ACTIO*, 11(3), 1-19.
<https://doi.org/10.3895/actio.v11n3.21610>

Copyright: This article is licensed under the terms of the Creative Commons Attribution 4.0 International Licence.



Recebido: 21 mar. 2026
Aprovado: 20 ago. 2026
DOI: <https://doi.org/10.3895/actio.v11n3.21610>

Como citar:

Azevedo, I. de M. R. & Oliveira, B. R. M. (2026). Ensinar e aprender sobre enzimas na graduação: possibilidades e desafios na docência em bioquímica. *ACTIO*, 11(3), 1-19.
<https://doi.org/10.3895/actio.v11n3.21610>

Direito autoral: Este artigo está licenciado sob os termos da Licença Creative Commons-Atribuição 4.0 Internacional.

