Received: 07|27|2024
Accepted: 02|25|2025

ENSAIO • Pesquisa em Educação em Ciências | 2025 | v27: e53640
DOI | http://dx.doi.org/10.1590/1983-2117-53640x

ARTICLE

REPRESENTATIVENESS OF MYCOLOGY IN INITIAL TRAINING IN BIOLOGICAL SCIENCES: A DOCUMENTARY ANALYSIS OF SYLLABI AND TEACHING MATERIALS

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ABSTRACT:

Historically, Mycology or Biology of Fungi has been built upon Botany, with strong influences from other fields such as Microbiology. This foundation is reflected in the structure of initial training programs in Biological Sciences. From this perspective, this study aimed to investigate the representation of Mycology-related content within biological knowledge in initial training in Biological Sciences. We conducted a documentary analysis of course syllabi in the field and materials used as bibliographic references in state universities in São Paulo. The results revealed the absence of specific courses on fungi, as well as the lack of specificity in the recommended bibliographic materials. We conclude that, to address these gaps, it is necessary to include specific Mycology courses in initial training programs and to promote the integration of knowledge with courses such as Ecology and Evolution. Additionally, encouraging the development of teaching materials focused on the specificities of fungi is essential.

Keywords:
Biology Education; Fungi; Professional Training.

REPRESENTIVIDAD DE LA MICOLOGÍA EN LA FORMACIÓN INICIAL EN CIENCIAS BIOLÓGICAS: ANÁLISIS DOCUMENTAL DE PROGRAMAS Y MATERIALES DIDÁCTICOS

RESUMEN:

Históricamente, la Micología se ha desarrollado a partir de la Botánica, con influencia de otras áreas como la Microbiología. Este marco histórico se refleja en la estructura de los cursos de pregrado en Ciencias Biológicas. En este contexto, el presente estudio tuvo como objetivo investigar la representatividad del contenido de Micología en los cursos de Ciencias Biológicas. Se realizó un análisis de los programas de los cursos y materiales bibliográficos utilizados en universidades estatales de São Paulo. Los resultados revelaron la falta de cursos específicos sobre hongos, así como la naturaleza genérica de los materiales de referencia. Se concluyó que, para abordar estas deficiencias, es esencial introducir cursos dedicados de Micología en los programas de pregrado y promover la integración de conocimientos con disciplinas como Ecología y Evolución. Además, es necesario fomentar la producción de materiales didácticos centrados en las especificidades del grupo fúngico.

Palabras clave:
Enseñanza de Biología; Hongos; Formación profesional.

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REPRESENTATIVIDADE DA MICOLOGIA NA FORMAÇÃO INICIAL EM CIÊNCIAS BIOLÓGICAS: UMA ANÁLISE DOCUMENTAL DE EMENTAS E MATERIAIS DIDÁTICOS

RESUMO:

Historicamente, a Micologia ou Biologia dos Fungos se construiu com base na Botânica e com forte influência de outras áreas, como a Microbiologia. Tal construção está refletida na estrutura de cursos de formação inicial em Ciências Biológicas. Nesta perspectiva, esta pesquisa buscou investigar a representatividade do conteúdo relacionado à Micologia no conhecimento biológico na formação inicial em Ciências Biológicas. Realizamos análise documental de ementas de disciplinas da área e de materiais utilizados como referências bibliográficas em universidades estaduais de São Paulo. Os resultados evidenciaram ausência de disciplinas específicas para os fungos, bem como, inespecificidade dos materiais indicados na bibliografia. Concluímos que, para superar essas lacunas, há a necessidade de incluir disciplinas específicas de Micologia em cursos de formação inicial e fomentar a integração de conhecimentos com disciplinas como Ecologia e Evolução. Ainda, faz-se necessário o estímulo à produção de materiais didáticos com enfoque nas especificidades do grupo dos fungos.

Palavras-chave:
Ensino de Biologia;
Fungos;
Capacitação Profissional.

INTRODUCTION

Fungi are organisms abundantly present across the planet, with a wide geographical and ecological distribution (Alexopoulos et al., 1996). Furthermore, fungal physiology is essential for the survival of life as we know it. Fungi are involved in food fermentation, culinary applications, and the active principles of various medications (Alexopoulos et al., 1996). Additionally, they contribute significantly to numerous ecological and evolutionary processes on Earth: The decomposition of organic matter and mutualistic associations with plants through mycorrhizae are fundamental for the maintenance of all terrestrial life (Schünemann et al., 2021). In this context, understanding fungi is essential for developing environmental conservation strategies and ensuring the survival of organisms as well as their interactions (Schünemann et al., 2021).

It is estimated that there are approximately 2.5 million species of fungi on the planet. However, only about 150,000 of them have been properly identified and cataloged, highlighting a significant disparity between what is known by humanity and the estimated fungal biodiversity (Niskanen et al., 2023). Despite their high diversity, studies dedicated to this group are remarkably limited compared to research focused on animals and plants.

The low representation of Mycology (the science that studies fungi) in education and research is strongly associated with the historical neglect faced during the development and establishment of this field as an independent area of knowledge (Estrela et al., 2023; Persijn, 2017). For a long time, fungi were classified as plants due to their sessile lifestyle (Whittaker, 1959, 1969). However, after the accumulation of evidence and the adoption of new approaches to the taxonomy of the group, proposals were developed to include fungi in their own taxonomic kingdom.

Many terms used to describe fungi, such as “fruiting bodies” and “basidiocarp,” have etymological roots in Botany, further complicating the conceptual separation between the two groups (Kirk et al., 2008). Consequently, one proposal that emphasizes the independence of fungi and contributes to their recognition in conservation efforts is the adoption of the term “Funga,” which refers to all fungi present in a given environment, similar to the terms “Flora” for plants and “Fauna” for animals (Kuhar et al., 2018).

Regarding the systematization of scientific knowledge in Mycology within professional training, fungal content in higher education curricula for Biological Sciences is often integrated alongside other groups of biological diversity (Persijn, 2017), frequently within courses such as Microbiology. The absence of a specific

course, as well as a lack of faculty experts in Mycology, can hinder the in-depth study of this issue in initial education programs.

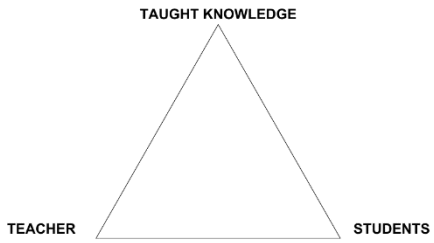
In this context, it is evident that the systematization of mycological knowledge remains deeply influenced by other fields, such as Botany and Microbiology. Moreover, understanding the material and epistemological gaps in Mycology studies during initial training in Biological Sciences is essential for developing didactic, curricular, and environmental conservation proposals. From this perspective, the general objective of this research was to investigate the representation of Mycology-related content within biological knowledge in the initial training of Biological Sciences programs. To achieve this objective, the following specific goals were established: (I) to catalog the bibliographic references of Mycology courses offered by state universities in São Paulo within Biological Sciences programs; and (II) to analyze the content of Mycology in these materials concerning language, chapter organization and main topics, figures, and the representation of the group's diversity.

THEORETICAL FRAMEWORK

To support the understanding of how Mycology content is organized in higher education, this section is structured around four main axes. First, we introduce Didactics as a field that organizes the relationships between scientific content, teachers, and students. Next, we describe Didactic Transposition, the process responsible for transforming scientific knowledge into teachable knowledge. Then, we discuss the principles that have shaped Mycology as a scientific course. Finally, we contextualize how this content is presented in teaching materials and courses related to initial training in Biological Sciences.

The Didactics of Natural Sciences, particularly Biology, have been established as a recent research field within the scope of studies on education and teaching practices. Didactics, as a field of knowledge, according to authors such as Caldeira and Bastos (2009), Chevallard (1998), Gatti (2017), and Libâneo (2010, 2013) has as its object of investigation, the important relationship between classroom practice, the specific knowledge of a particular area, and pedagogical knowledge, to be mediated by the teacher. Chevallard (1998) refers to this articulation as the Didactic System (Figure 1).

Figure 1. Representation of Chevallard's Didactic System.



Source: Adapted from Chevallard (1998).

From this perspective, Didactics is established as a field of knowledge that presents a complex articulating relationship in the teaching of Natural Sciences. This complexity can be identified by the challenging task of relating pedagogical knowledge and scientific knowledge specific to a given field.

In the case of Mycology course in professional training, for example, there is a significant difficulty in articulating the axes of the Didactic System due to various factors: The late establishment of this science, the low number of fungi faculty experts, the few courses that address this group in the initial training of biologists,

and the rapid and constant changes in scientific knowledge regarding the fungal group (Estrela et al., 2023; Persijn, 2017). As a result, the study of fungi becomes underrepresented in the initial training of Biological Sciences programs.

Moreover, teaching and learning processes are mediated by language, both in its written form in teaching materials and orally in the classroom. Thus, biological phenomena are represented through words. In the case of phenomena that occur over evolutionary time and at the molecular level, which require a high degree of abstraction, the role of language-mediated by words is fundamental, considering the difficulty in accessing them directly.

Furthermore, language-mediated by words has the limitation of potentially leading to misconceptions (Ceschim et al., 2020). The authors established criteria to qualify these misconceptions in Biology Education (Ceschim et al., 2020). The criteria were grouped into three categories: (1) the relation between thought and language, (2) the nature of human thought, and (3) the application of biological knowledge. To achieve the objectives of this work, the focus is on figures of speech and polysemy, which can create or reinforce misconceptions, thus falling under category 1. In addition to polysemy, the figures of speech identified by Ceschim et al. (2020) that have the potential to generate or reinforce misconceptions are: metaphor, metonymy, antithesis, and personification. Misconceptions can be present in various teaching resources. Below, we highlight textbooks as an important resource that arises from a process of Didactic Transposition, and that may present misconceptions.

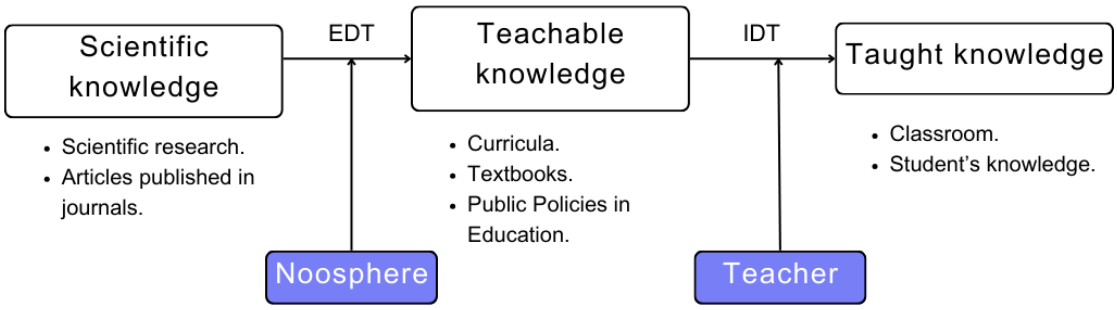
Various teaching resources are used to mediate teaching and learning processes throughout basic and higher education: teaching materials. According to Bandeira (2009, p. 14, our translation), "teaching material can be broadly defined as pedagogical products used in education and, specifically, as instructional material developed for didactic purposes." Some examples include: textbooks, illustrative guides, games, and laboratory manuals (Bandeira, 2009; Krasilchik, 2019).

One of the main teaching materials used throughout students' education is the textbook. The role of this resource is of great importance, as it is responsible for mediating written communication between scientific content, students, and teachers (Krasilchik, 2019). Textbooks, in many training programs and even in basic education, serve as one of the defining elements of the curriculum content to be addressed in a given course (Krasilchik, 2019). The content, already organized and selected (since it has undergone External Didactic Transposition), facilitates the development of didactic sequences, for example.

Considering that scientific knowledge is produced within a research context, in order to be taught in the classroom, it must first be transformed and adapted for this purpose. During Didactic Transposition, modifications occur in "scientific knowledge" (Figure 2). Initially, External Didactic Transposition occurs, which adapts scientific knowledge into "teachable knowledge," the latter found in materials such as handouts and textbooks, for example. The group responsible for the External Didactic Transposition is collectively referred to as the "Noosphere," an intellectual dimension that can be represented by researchers in a particular field, textbook authors, people involved in public policy development, teachers, and textbook publishers, among others. The Noosphere selects the content to be covered and determines how it should be presented (Chevallard, 1998; Senna et al., 2020). In this stage of Didactic Transposition, there is a decontextualization and depersonalization of scientific knowledge, meaning that knowledge is detached from the context and objectives that initially supported it, and the individuals responsible for the work are typically not identified (Chevallard, 1998; Senna et al., 2020).

The teachable knowledge is what is worked on in the classroom by the teacher and, therefore, it undergoes Internal Didactic Transposition. The teacher is responsible for selecting what will be taught, thus determining the learning objectives that students should achieve (Senna et al., 2020). Internal Didactic Transposition transforms the teachable knowledge into taught knowledge, which is the knowledge that resides in the students' subjectivity after learning (Ceschim et al., 2020; Senna et al., 2020).

Figure 2. Representative diagram of Didactic Transposition.



Note. EDT = External Didactic Transposition. IDT = Internal Didactic Transposition.

Source: Elaborated by the authors based on Chevallard (1998).

However, it is important to emphasize that textbooks should not be understood as the only resource available in teaching and learning processes and that they have limitations. One of the main limitations of textbooks, especially regarding higher education programs, is what we refer to as the Didactic Transposition Delay (Carvalho, 2009).

As highlighted, Didactic Transposition presents distinct stages carried out by various agents. The Didactic Transposition Delay entails certain issues that may slow down this process (Carvalho, 2009). The time between the production of specific scientific knowledge and its incorporation into teaching materials depends on the axiological choices of the Noosphere (Krasilchik, 2019). In cases where Didactic Transposition Delay is a determining factor, the teachable knowledge may become obsolete.

Considering that scientific knowledge is the starting point for Didactic Transposition, we will now explore the development of Mycology as a scientific course to support the understanding of its aspects in teaching.

Sciences represent a field of human knowledge that is established as a technology or an intellectual system (Fourez, 1995). Science has two dimensions: The first is the material dimension, which corresponds to the physical environment that supports the development of this knowledge, such as libraries housing books on a particular course, laboratories conducting research on the object of study, and scientific journals (Fourez, 1995, pp. 94–95). The second is the intellectual dimension, which refers to the establishment of science as an independent scientific course (Fourez, 1995, p. 105).

Scientific courses are determined based on mental organizations that are developed into disciplinary matrices. These matrices (or paradigms) are used to classify the world and find ways to approach it with representations (Fourez, 1995). Thus, courses are founded around a research object that has its own characteristics, distinct from those of objects in other courses (Fourez, 1995).

Based on research questions and the formation of paradigms, Mycology was established as the field focused on the study of the Fungi Kingdom. However, institutionally, Mycology is still organized based on Botany and Microbiology: in research institutes, university departments, scientific courses, curricula, and even in the scientific language used to refer to the group. A notable example of this organization is the nomenclature of scientific names, which is regulated by the *International Code of Nomenclature for Algae, Plants, and Fungi*. Until 2011, this Code was known solely as the *International Code of Nomenclature for Plants*. Even though fungi were included, they were only recognized in the title of the International Code of Nomenclature in the 21st century (Kuhar et al., 2018; Turland et al., 2018).

As previously described, there are significant challenges in establishing Mycology as an autonomous science and its representation in the initial training of Biological Sciences programs. A study conducted by Persijn (2017) in the state of Goiás revealed that, out of a total of 32 programs analyzed across 22 Higher Education Institutions offering initial training in Biological Sciences, only three had specific courses dedicated to the study of fungi. Most of the teachers interviewed in the study were from areas of specialization distinct from Mycology, and the content on fungi was addressed in generalist courses such as Microbiology and Botany (Persijn, 2017).

Estrela et al. (2023) investigated the perceptions of students in the initial training of Biological Sciences programs at state universities in São Paulo regarding careers in Mycology. Although the majority of the students who participated in the study view Mycology as a potential field for biologists, only 12% feel prepared to work in the field after completing their initial training studies. Furthermore, the legislation from the Federal Council of Biology (CFBIO) appears to be non-specific regarding work with fungi, focusing on the group only in terms of its environmental aspects, such as cultivation, management, and commercialization (Estrela et al., 2023).

The implications of these issues can be reflected in a low number of specialists in the field and a reinforcement of the historical neglect faced by the group (Grube et al., 2017). This lack of knowledge, resulting from the low number of specialists capable of identifying and describing fungal species in various ecosystems, can lead to the extinction of species before they are even described and to a lack of measures for the environmental conservation of the group (Grube et al., 2017).

Moreover, the high number of fungal species that do not produce visible reproductive structures also raises significant concerns for the preservation of ecosystems, as these species are often not even considered (Grube et al., 2017).

METHODOLOGY

The research is qualitative in nature and is characterized by the understanding and interpretation of the collected data. It is descriptive in nature, focusing on a deep understanding of meanings regarding a specific phenomenon, without the aim of producing generalizations (Patton, 2014). Among the possible qualitative research approaches, this investigation employed documentary analysis and content analysis.

Bibliographic materials from Mycology courses and others that address the fungal group alongside other organisms, such as Microbiology courses, from the state universities in São Paulo offering Biological Sciences programs, were analyzed. In this regard, this stage of the research involves a documentary analysis of syllabi and teaching materials (Flick, 2009; Patton, 2014).

First, a search was conducted for syllabi of Mycology courses and others related courses from the Biological Sciences programs at state universities in São Paulo. At this stage, it was analyzed whether the program offered a specific course for this group, and a list was created of the teaching materials used for Mycology content. During this process, it became necessary to establish selection criteria for the inclusion and exclusion of courses and teaching materials that were analyzed in this study.

Three inclusion criteria were developed for the courses analyzed, as follows: (I) the courses should belong to the mandatory curriculum of the Biological Sciences programs at state universities in São Paulo; (II) the courses should contain at least one of the following keywords in their titles—fungi, microbiology, botany, diversity, systematics, fermentation, and/or mycology; (III) in the courses' teaching plans that met the first two criteria, a search was conducted for the following keywords—fungi, mycology, *fungos*, and/or *micologia*.

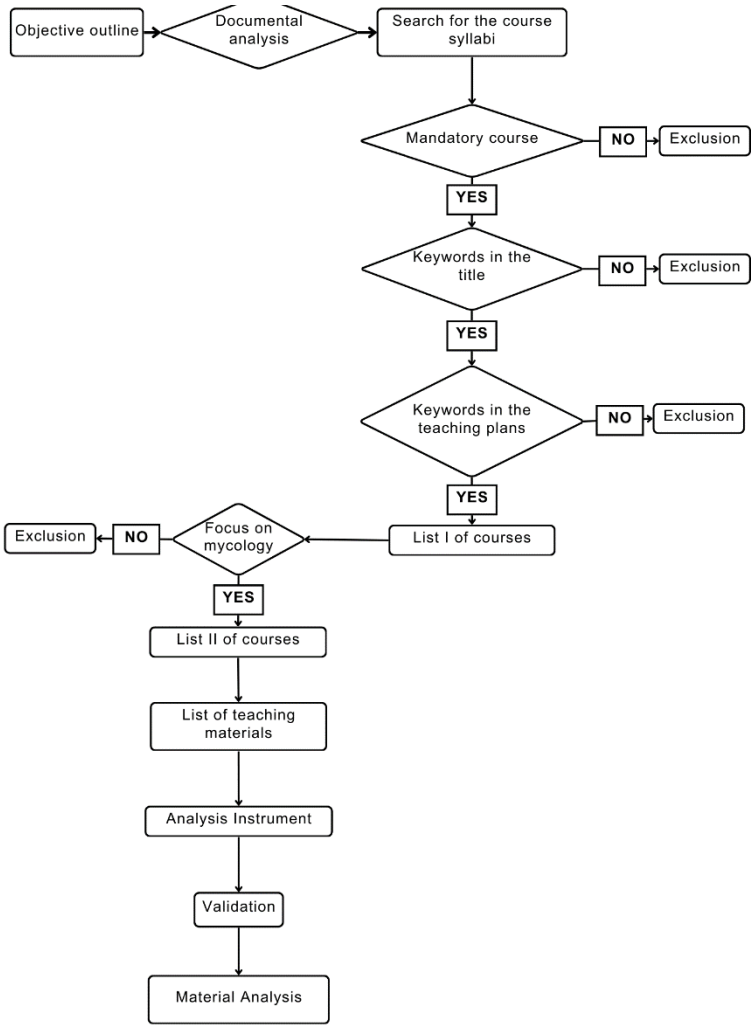
After this stage of the research, it became necessary to develop exclusion criteria to more specifically delimit which courses focused on Mycology as one of their main themes. Thus, two exclusion criteria were established for the courses included in the study: (I) courses that emphasized areas other than Mycology (for example, Environmental Microbiology); (II) courses that did not include the study of Mycology as one of the main focuses of the program (for example, Biological Systematics and Biodiversity of Life). In these courses, the focus of the syllabi (i) is not concentrated on aspects of Fungal Biology, and (ii) addresses applied aspects

of Mycology. Although fungi are present as part of biodiversity groups, they do not represent a central part of the development of these courses. In the case of Environmental Microbiology, for example, the emphasis shifts away from Mycology by generally mentioning processes such as biodegradation, bioremediation, and soil formation. In this sense, we emphasize that the objective of the research is focused on courses that address General Mycology rather than its applications. Programs such as Industrial Microbiology, which presents physiological aspects of fungi applied to industrial activities, were also excluded. In the case of the courses on Biological Systematics and Biodiversity of Life, the justification for exclusion is based on the fact that the diversity kingdoms are only mentioned without an in-depth exploration of any of them.

Next, a search was conducted for the textbooks used as bibliographic references in the courses selected in the previous stage. The teaching materials were cataloged into a list for further analysis. Based on the complete list of bibliographic references used in the courses that met the criteria established in the previous stage of the research, selection criteria for the analysis of teaching materials were developed. The inclusion criteria were: (I) the material belongs to the mandatory courses of the Biological Sciences programs at state universities in São Paulo; (II) it is a textbook; (III) the textbook is part of the required reading for the course; (IV) the selected textbook is available on the virtual platforms *Minha Biblioteca*, *Biblioteca Virtual*, or is physically available at the Bauru campus library of UNESP or other campuses. The most recent and updated editions of the selected textbooks were analyzed. In cases of repetition of a textbook in the bibliographic references, only the most recent edition available was analyzed. Textbooks that did not cover Mycology content, such as Zoology and Phycology textbooks, were excluded. The exclusion criterion for these textbooks was due to the absence of chapters on fungi, such as Franceschini et al. (2018), which is exclusively about algae, and Brusca et al. (2018), a Zoology textbook that addresses animal groups and protozoa. These textbooks appeared on the initial list because they are found as references for generalist courses such as Protists and Fungi. Only one chapter from each textbook was analyzed, and the chapters chosen for analysis were those that introduce the fungal group or discuss its systematics.

An analysis instrument was developed based on the nature of the concepts presented. The categories of this instrument are mixed, with some categories constructed *a priori* and others constructed *a posteriori*, based on the results found during the validation process of the analysis instrument (Patton, 2014). The methodological pathway is simplified in the flowchart below (Figure 3).

Figure 3. Flowchart of the methodological pathway.



Source: Developed by the authors.

Four categories were developed *a priori*: (I) specificity of the material in relation to the fungal group, (II) organization and language, (III) figures, and (IV) systematics. These analysis categories were established based on the research objectives and theoretical frameworks. Categories (I) and (IV) pertain to the nature of Mycology concepts and their historical construction, as discussed in the theoretical framework section. For a proper understanding of Fungal Biology, it is essential to recognize fungi as an independent group in taxonomy, as well as the most recent classifications of the group, hence the inclusion of these analysis categories. Categories (II) and (III) are based on the relationship between thought and language and the potential for misconceptions (Ceschim; Ganiko-Dutra; Caldeira, 2020). Thus, we proposed investigating these aspects that can influence learning either positively or negatively, depending on how they were developed in the teaching materials.

The content analysis followed the criteria established by Patton (2014). A table was developed with five columns: (1) index of the analyzed textbooks numbered with the code TB; (2) specificity of the textbooks; (3) analysis of the language used in the textbooks; (4) analysis of the figures used in the textbooks; and (5) taxonomic classification used to divide the Fungi Kingdom, a category named Systematics.

Based on the results obtained from the analysis instrument for the textbooks, patterns, and themes were sought in each of the analysis categories, and codes were subsequently assigned to the patterns identified

(Patton, 2014). For the specificity category, the textbooks were categorized into three groups: type of textbook (possible codes—Bot = Botany textbook; Mic = Microbiology textbook; Sys = Systematics textbook; Myc = Mycology textbook; GenBio = General Biology textbook); presence or absence of a chapter exclusively dedicated to fungi (possible codes—PExC = presents an exclusive chapter; NExC = does not present an exclusive chapter); presence or absence of emphasis on the fungi group, such as chapters dedicated to diseases caused by fungi (possible codes—PEm = presents emphasis; WEm = without emphasis); and presence of various and explained examples (Ed = various and explained examples; Ec = cited examples). The codes are mutually exclusive, so once a textbook is categorized with one code (*e.g.*, "Mic"), it cannot be included under another code related to the type of textbook (*e.g.*, "Myc"). The language category analyzed: terminology (code—TBot = terminology based on Botany); adequacy of the language recognizing the autonomy of the Fungi Kingdom (possible codes—AL = adequate language; IL = inadequate language); presence or absence of misconceptions and their types (NMc = no misconception; PMc = presents misconception). Textbooks classified with the code Mc have subcategories related to the possible types of misconception found. In this case, code overlap may occur (PeMc = personification misconception; MeMc = metaphor misconception; AnMc = antithesis misconception; MoMc = metonymy misconception).

For the figures category, the analysis focused on the presence of real images and coloration. In this regard, the codes related to the type of image were presented (possible codes—RI = real images; R = representations), where representations include illustrations, diagrams, drawings, among others. An analysis was also made regarding coloration (possible codes—BWI = black and white images; TC = true colors; IFC = indicated fantasy colors; NFC = non-indicated fantasy colors). In the systematics category, the textbooks were classified according to: convergence with recent taxonomic proposals (DNF = does not follow the taxonomic proposals considered as approaching a consensus [*cf*. Spatafora et al., 2017]; IS = indicates the source used as a reference for classifying the group; NIS = does not indicate the source used as a reference for classifying the group).

The analysis instrument was validated through a pilot analysis of its effectiveness. The validation was carried out by two individuals: a graduate in Biological Sciences and an undergraduate who also conducts research in the field of Mycology. Each evaluator received the original version of the analysis instrument and the title of a textbook that could be accessed through the *Minha Biblioteca* platform. There was no communication between the evaluators during the validation process, and each one analyzed a different teaching material.

After the validation by the evaluators, the instrument was improved. The figures category underwent the most modifications, with the question "Are the descriptions of the figures adequate?" being replaced by three new analysis questions: "Do the figures indicate the type of image? (photography, micrograph, diagram, etc.)," "Do the figures provide brief descriptions, not too lengthy?," and "Are the image sources indicated?". In order to allow for the categorization of the figures in the categorical framework, they were analyzed based on two categories: (1) Are the figures photographs/micrographs (real images) or representations (illustrations/diagrams/flowcharts)?; (2) Are the figures presented in black and white? Do color figures show real colors? If fantasy colors are used, are they indicated? The original version of the analysis instrument, the evaluators' validations, and the final version of the analysis instrument can be accessed in the journal's research data release on the Dataverse. In addition to these data, we also provide information on the availability of the syllabi on Dataverse.

RESULTS

Based on the criteria established for the selection of courses from the state universities of São Paulo, a list was created with the total number of courses. A total (*n*) of 24 Biological Sciences programs from the three state universities of São Paulo were analyzed: two programs from the University of Campinas (UNICAMP), nine programs from the University of São Paulo (USP), and 13 programs from the São Paulo State University "Júlio de Mesquita Filho" (UNESP).

After applying the exclusion criteria, a total of 17 courses were selected. Microbiology courses predominated in the study of fungi. Out of the final list, 13 of the 17 courses were related to Microbiology. The remaining four courses were titled “Protists and Fungi”: diversity courses that present fungi alongside the group of Protists. The courses can be seen in Table 1.

Table 1. Courses that include the study of fungi at the state universities of São Paulo after applying the exclusion criteria.

Index	Course Title	University	Campus
C01	Microbiology I	Unicamp	Campinas
C02	Basic Microbiology	USP	São Paulo
C03	General Microbiology	USP	Piracicaba
C04	Microbiology	USP	Ribeirão Preto
C05	Basic Microbiology	Unesp	Assis
C06	Protists and Fungi	Unesp	Assis
C07	Protists and Fungi	Unesp	Bauru
C08	Basic Microbiology	Unesp	Bauru
C09	Basic Microbiology	Unesp	Botucatu
C10	Basic Microbiology	Unesp	Ilha Solteira
C11	Protists and Fungi	Unesp	Ilha Solteira
C12	Microbiology	Unesp	Jaboticabal
C13	Microbiology	Unesp	Rio Claro
C14	Basic Microbiology	Unesp	São José do Rio Preto
C15	Protists and Fungi	Unesp	São José do Rio Preto
C16	Microbiology	Unesp	São Vicente
C17	Basic Microbiology	Unesp	São Vicente

Note. C = Course.
Source: Elaborated by the authors (2024).

None of the universities analyzed presented a mandatory course that exclusively addresses the Fungi Kingdom based on the criteria applied. Regarding the number of courses after applying the inclusion and exclusion criteria, only one mandatory course that covers fungi remained in the sample at UNICAMP, one at each campus of USP, and at UNESP, only the Botucatu, Jaboticabal, and Rio Claro campuses had a single course, while the remaining campuses offered two courses.

The number of one or two courses per program related to Mycology remains low when compared to other areas of biological diversity.

The bibliographies of the courses collectively included 56 references: two scientific articles and 54 textbooks. Both scientific articles were related to the general taxonomy of eukaryotes. Of the textbooks, 21 were in Microbiology, 11 in Mycology, 11 in industrial applications, five in Botany and/or Phycology, three in Zoology, two in Systematics, and one in General Biology. The references were published between 1972 and 2022. The list of analyzed textbooks can be seen in Table 2.

Table 2. List of analyzed teaching materials.

Index	**Textbook**
T01	Alexopoulos, C. J., Mims, C. W. & Blackwell, M. (1996). *Introductory mycology* (4th ed.). New York: John Wiley & Sons, Inc.
T02	Black J. G. & Black, L. J. (2021). *Microbiologia*: Fundamentos e perspectivas (10th ed.). Rio de Janeiro: Guanabara Koogan.
T03	Bononi, V. L. R. (Org.). (1998). *Zigomicetos, basidiomicetos e deuteromicetos: noções básicas de taxonomia e aplicações biotecnológicas.* São Paulo: Instituto de Botânica, Secretaria de Estado do Meio Ambiente.
T04	Carlile, M. J., Watkinson, S. C. & Gooday, G. W. (2001). *The fungi* (2nd ed.) San Diego: Academic Press.
T05	Esposito, E. & Azevedo, J. L. (2010). *Fungos: uma introdução à biologia, bioquímica e biotecnologia* (2nd ed.). Caxias do Sul: Educs.
T06	Madigan, M. T., Martinko, J. M., Bender, K. S., Buckley, D. H. & Stahl, D. A. (2016). *Microbiologia de Brock*. Porto Alegre: Artmed, 2016.
T07	Margulis, L. & Schwartz, K. V. (2012). *Cinco reinos: um guia ilustrado dos filos da vida na Terra.* (3rd ed.). Rio de Janeiro: Guanabara Koogan.
T08	Moore-Landecker, E. (1996). *Fundamentals of the fungi.* (4th ed.). New Jersey: Prentice Hall.
T09	Oliveira, E. C. (2003). *Introdução à Biologia Vegetal*. (2nd ed.). São Paulo: EDUSP.
T10	Pelczar, J. R., Michael, J., Chan, E. C. S. & Krieg, N. R. (1996). *Microbiologia: conceitos e aplicações.* (2nd ed., Vol. 1). São Paulo: Makron Books.
T11	Putzke, J. & Putzke, M. T. L. (1998). *Os reinos dos fungos.* (Vol. 1.). Santa Cruz do Sul: Edunisc.
T12	Raven, P. F., Evert, R. F. & Eichhorn, S. E. (2014). *Biologia vegetal.* (8th ed.) Rio de Janeiro: Guanabara Koogan.
T13	Smith, G. M. (1979). *Botânica criptogâmica*: Algas e fungos. (3rd ed., Vol. 1). Lisboa: Fundação Calouste Gulbenkian.
T14	Tortora, G. J., Funke, B. R. & Case, C. L. (2017). *Microbiologia.* (12th ed.). Porto Alegre: Artmed.
T15	Trabulsi, L. R. & Alerthum, F. (2008). *Microbiologia.* (5th ed.). São Paulo: Atheneu.
T16	Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V. & Orr, R. B. (2022). *Biologia de Campbell*. (12th ed.). Porto Alegre: Artmed.
T17	Vermelho, A. B., Pereira, A. F., Coelho, R. R. R. & Souto-Padrón, T. (2019). *Práticas de Microbiologia*. (2nd ed.). Rio de Janeiro: Guanabara Koogan.
T18	Xavier-Filho, L., Legaz, M. E., Vicente-Córdoba, C. & Pereira, E. C. (2006). *Biologia de líquens.* Rio de Janeiro: Âmbito Cultural.

Note. T = Textbook.
Source: prepared by the authors.

Of the total number of textbooks used as references in the selected courses, 18 met the inclusion and selection criteria for analysis. Regarding the teaching materials, of the 18 textbooks, seven were specific to Mycology, six were related to Microbiology, three to Botany, one to General Biology, and one to Systematics

In terms of the specificity of the analyzed teaching materials, it was observed that most of them contained a chapter dedicated to fungi or were entirely focused on Mycology. Five of the textbooks did not have exclusive chapters for the Fungi Kingdom, and these were from the Microbiology category. Overall, the Mycology textbooks presented various emphases throughout the chapters, such as in T03, which deeply addresses fungal systematics, albeit outdated due to the production and publication year of the material (Bononi, 1998).

All of the analyzed teaching materials presented terms and affixes with botanical etymology. The most recurrent terms included: rhizoids, fruiting bodies, roots followed by the suffix -carp (ascocarp and basidiocarp, for example), the term vegetative, thallus, and roots followed by the suffix -phyte (such as saprophytes). The etymology of the terms was verified using the Dictionary of Fungi by Kirk et al. (2008). In addition to these terms, the analysis highlighted the use of the terms "perfect," "imperfect," and "higher" or "lower" fungi, which corresponds to an erroneous evolutionary view that considers more derived groups as more evolved.

The textbooks T09, T10, T13, T14, T16, T17, and T18 present some form of misconception. The following excerpts demonstrate the types of misconceptions and their didactic implications. In the textbook T09, the excerpt "fungi that lichenize modify their thalli to trap and cultivate algae that will provide them with food. As a result, the thallus of lichens resembles plants rather than fungi" (Oliveira, 2003, p. 247, our translation) indicates personification and metaphor (Ceschim et al., 2020) by referring to the modification of lichen thalli and the "trapping of algae."

The textbook T10 presents metaphor and metonymy in the following excerpt: "With great magnification, molds appear as a miniature forest with many regions" (Pelczar et al., 1996, p. 124). The metaphor that associates molds with forests could reinforce the idea that fungi are plants. Additionally, in T13, fungi are placed within the Plantae Kingdom (Smith, 1979).

Other examples of personification are present in several excerpts from T16, such as: "Just like mutualistic fungi, parasitic fungi absorb nutrients from living host cells, but do not provide benefits in return" (Urry et al., 2022, p. 669, our translation). There is also an antithesis in T17, which presents a dichotomous view of microorganisms.

> However, it is important to remember that microbes are also great allies of humans, as they are responsible for a wide range of processes, from the production of food, including wines, breads, cheeses, and yogurts, to the maintenance of chemical element cycling, such as nitrogen, on the surface of the Earth (Vermelho et al., 2019, p. 2, our translation).

Finally, the textbook T18 also presents several examples of personification, such as in: "In fact, the idea that fungi 'enslave algae, as we do with cattle' was initially proposed by Schwender in 1867, when he discovered that lichens are associations of fungi and photobionts" (Xavier-Filho et al., 2006, p. 27, our translation).

The analysis of the figures indicates the following results: T13 does not have figures in the analyzed chapter; of the remaining textbooks, 16 feature representations, with T04 being the only one without representations (Carlile et al., 2001; Smith, 1979). The analysis highlights that 13 textbooks include real images. Regarding color analysis, nine materials present black and white images, while the others feature colored figures, with eight textbooks displaying images with real colors, and seven containing figures in fantasy colors. Of the latter, five did not indicate artificially colored figures.

None of the textbooks analyzed followed the taxonomic proposal of Spatafora et al. (2017) with eight fungal phyla, or that of Tedersoo et al. (2018) with 18 phyla, which are considered in this investigation to be the most recent and closest to consensus. A wide range of authors was used as references for taxonomy, such as Alexopoulos et al. (1996), Hawksworth and Lücking (2017), and Margulis and Schwartz (2012), which correspond to older systematic proposals. The most commonly found classification was that of four phyla: Chytridiomycota, Zygomycota, Ascomycota, and Basidiomycota. Another frequently presented classification divides fungi into groups without taxonomic character: zygomycetes, ascomycetes, basidiomycetes, and deuteromycetes. Some factors that may justify the absence of the more recent classifications include: most of the bibliographic references were published prior to the aforementioned proposals, and among the more recent

textbooks, the lack of specific mycology literature in the development of the materials, as well as the failure to adopt the mentioned systematic proposal due to the large number of disseminated proposals, in addition to Didactic Transposition Delay.

DISCUSSION

Regarding the list of courses, the observed scenario indicates two implications regarding the organization of mycology in the courses at public universities in the state of São Paulo: (1) fungi, as a biodiversity group of study, are present in only a few courses, and (2) all the courses that include fungi share their syllabus with other groups of biological diversity. These findings support the low representativeness of fungi in the initial training of Biological Sciences, as highlighted by Estrela et al. (2023) and Persijn (2017). The lack of a specific course on the Fungi Kingdom results in superficial coverage of these organisms and their ecological, physiological, and evolutionary relationships, affecting the biological knowledge of future biologists and educators. Therefore, it would be desirable to implement independent courses specifically focused on fungi taught by faculty experts (Persijn, 2017). For this to happen, there is a need for the establishment of certificate programs in the area and investment in curricular changes in the initial training of Biological Sciences programs.

Moreover, since fungi are presented within microbiology courses in a large portion of the analyzed programs, there is a need for a deeper understanding of mycological concepts in the training of these educators. Postgraduate programs in Microbiology should contribute to this regard by establishing courses and research lines focused on Mycology, as well as stipulating the hiring of mycologists to formalize and institutionalize Fungal Biology as an independent field that requires specialized professionals.

In relation to the material dimension of Mycology as a science (Fourez, 1995), it is important that the lists of textbooks used as references be updated, and that materials dedicated to Mycology be included in generalist courses. This way, students can engage with more specific and up-to-date mycological references. Furthermore, due to the rapid advances in the taxonomic organization of the group, it is fundamental that students recognize the most recent proposals.

Regarding the curriculum organization, it is noteworthy that no Botany courses include the Kingdom Fungi in their curricula, illustrating that the recognition of the monophyletic nature of the group in relation to plants is already reflected in course syllabi. However, with respect to the teaching materials on fungi, there are still references from the field of Botany that dedicate themselves to the study of the group, including the book *Botânica criptogâmica* by Smith (1979), which treats fungi as a group within the Kingdom Plantae. The inclusion of this book among the bibliographic references is problematic since it places fungi within the Kingdom Plantae, failing to acknowledge the well-established monophyletic nature of the group.

Furthermore, the association of Mycology with Botany textbooks contributes to potential misconceptions and fallacies in teaching (Ceschim et al., 2020). This perpetuates the mistaken perception that fungi are plants and the continued use of terminology based on Plant Biology to describe fungal structures and processes. Additionally, by sharing space with other biodiversity groups, specific aspects of fungal biology are not adequately presented due to material limitations, such as the number of pages in textbooks and the time constraints to cover different biodiversity groups (Bandeira, 2009; Krasilchik, 2019).

Moreover, the association of Mycology with courses that share space with other organisms, such as Microbiology and “Protists and Fungi,” can be problematic, as fungi do not have a close evolutionary relationship with bacterial groups or Protists, which are known for their controversial taxonomy due to being a paraphyletic group. This curricular organization is underrepresented when compared to courses focused on the study of Zoology and Botany. Universities tend to offer a much higher number of courses dedicated to animals and plants, and in some cases, these are even more specific, such as the disciplines of Plant Morphology, Plant Systematics, and Plant Physiology found at UNESP.

In addition to offering specific Mycology courses, it is essential for existing courses to become more integrated, presenting aspects of fungal biology in greater depth within courses such as Ecology, Evolution, and General Systematics. Carvalho et al. (2020) highlight the potential of reorganizing biological content based on

structuring concepts in Biology. This way, courses could be organized in a less fragmented manner, with more room for intersections between different groups of biological diversity and their relationships. However, there are limitations to the highlighted proposals, as the low number of Mycology faculty experts (Grube et al., 2017) makes it difficult to implement deep connections between generalist courses and the creation of exclusive courses. This sets up a feedback problem: Since there are no specific courses in Mycology, there is no demand for the hiring of faculty experts, which maintains the low representativity of fungi in the initial training of Biological Sciences.

Regarding the language used in the textbooks and possible misconceptions arising from Didactic Transposition (Chevallard, 1998; Senna et al., 2020), a framework can be developed with the polysemy and recurring figures of speech. The term spore is polysemic because, although the same term is used to refer to groups of bacteria, fungi, and plants, it assumes distinct characteristics in each biological kingdom. Metaphors are used to compare conceptual objects that share similarities and incompatibilities: similarities are emphasized, while incompatibilities are suppressed (Lakoff & Johnson, 2008). The metaphor of comparing fungal mycelium to a root can lead to misconceptions that reinforce the view that fungi are plants, when the only similar functions between these structures are substrate attachment and nutrient absorption.

Many students perceive that the mushroom or any reproductive structure visible to the naked eye represents the fungus as a whole (Largent, 1986). This mistaken interpretation is an example of metonymy. In addition to this, the antithesis present in the utilitarian view of fungi contributes to the pessimistic perception of the group, referring to pathogenic species as "enemies" of humans (Schünemann et al., 2021). Finally, the personification in the excerpt from Urry et al. (2022, p. 667) attributes intentionality to fungi, highlighting their ability to "repay actions" that seek their own benefit—human-like characteristics. The examples cited were compiled in the table below and are commonly found in textbooks or in the discourse of teachers and students.

Table 3. Polysemy and figures of speech with potential to generate or reinforce misconceptions.

Figure of Speech	Definition	Examples in Mycology
Polysemy	A linguistic unit is assigned multiple meanings, which may or may not be related.	Fungal spores and bacterial spores.
Metaphor	Understanding one conceptual domain based on terms from another; there is incompatibility between parts of the concepts.	Comparison between the underground mycelium of fungi and the roots of plants.
Metonymy	Representation of one term based on another, "part for the whole."	Perception that the reproductive body of fungi represents the entire organism.
Antithesis	A binary and dichotomous view of biological phenomena.	Fungi as friends or enemies in relation to their applications for humanity.
Personification	Attribution of intentionality and human characteristics to biological processes and distinct groups of organisms.	"Mutualistic fungi absorb nutrients from a host organism but repay with actions that benefit it" (Urry et al., 2022, p. 667, our translation).

Source: elaborated by the authors based on Ceschim et al. (2020).

Since the popularization of the term Funga and modifications to the *International Code of Nomenclature for Fungi, Algae, and Plants*, there has been an intensification in the discussion of terms that reflect the independence of fungi as a distinct group within biodiversity (Kuhar et al., 2018; Turland et al., 2018). Terms with botanical etymology have, in many cases, already been replaced by alternatives that reinforce the monophyletic nature of the Fungi Kingdom and are well-established in mycological scientific literature. However, in many instances, these terms have not yet made their way into teaching materials. Some of the terms cited throughout the work and found in textbooks could be replaced with: fungal body, reproductive bodies/reproductive structures, sporoma/basidioma/ascoma, somatic mycelium, reproductive mycelium/aerial mycelium, saprobic fungi. These modifications do not rely on botanical etymology and are more suitable for teaching and representing fungi as a distinct group from plants (Kirk et al., 2008).

The analysis of the textbooks also demonstrated low specificity and inadequate alignment with the scientific literature in the field of Mycology. The large number of Microbiology and Botany textbooks that address the Kingdom of Fungi do so superficially, providing some examples to explain its ecology and physiology but without delving into these topics in depth. Among the textbooks specifically focused on Mycology, there is a notable lack of updated references and even a low number of materials in Portuguese. This issue may be related to the low number of translations of foundational materials from other languages and the limited production of Brazilian teaching materials that specifically address fungi, as well as Didactic Transposition Delay, which limits the availability of updated materials, as highlighted by Carvalho (2009).

It is necessary to include pedagogical guidelines in teaching materials that highlight the possible misconceptions found in those materials, as well as the further qualification of teachers so they can recognize these misconceptions when they encounter them. Additionally, it is important that the text itself specifies when to use figures of speech, minimizing the impacts of misconceptions inherent in the language used to explain biological phenomena (Ceschim et al., 2020).

In general, a variety of figures are included in the analyzed books. The absence of figures in T13 may lead to difficulties for students in recognizing fungi in natural environments (Smith, 1979). Books with artificially colored figures without indications may reinforce misconceptions. For example, T15 presents hyphae colored green without indicating that the colors are fictional, which may contribute to the understanding that fungi have chlorophyll (Trabulsi & Alerthum, 2008).

The systematic proposals found in the analyzed textbooks, often presenting four phyla or groups as in the results, do not align with the current phylogenetic system of fungi. Phyla such as Chytridiomycota and Zygomycota are poly/paraphyletic, and the group of deuteromycetes does not represent a natural grouping. However, due to Didatic Transposition Delay, lack of updated materials, and the absence of a robust scientific consensus regarding the classification of fungi, many recent textbooks continue to adopt these classifications, citing them as historical, as seen in the case of Black and Black (2021).

Therefore, the obsolescence of the textbooks listed in the bibliographies of the courses is an indicator of outdated Mycology teaching. The production and translation of more recent materials, combined with the proper recognition of fungi in specific courses, is one of the short-term measures that can be implemented in the initial training of Biological Sciences.

FINAL CONSIDERATIONS

This study achieved its objective of investigating the representativeness of Mycology in the initial training of Biological Sciences programs at public universities in the state of São Paulo. The research conducted revealed that the low representativeness of fungi persists in the curricular organization of initial training of Biological Science programs and in the textbooks used as references for courses that include Mycology.

We emphasize and advocate for the incorporation of courses that exclusively address fungi, encompassing the evolutionary, ecological, physiological, and morphological aspects of the group. This structure contributes to a deeper theoretical understanding of the biology of fungi. Furthermore, there is a clear need for more integrative curricular proposals in the initial training of Biological Sciences programs, aiming to include various biodiversity groups in courses such as Ecology and Evolution, for example.

Regarding teaching materials, there is a need for the production and translation of more up-to-date and specific books in the field of Mycology teaching, as well as the adaptation of these materials to the scientific consensus of the mycological community. This includes the standardization of terms (for example, replacing “sporocarp” with “sporoma”) and the phylogeny of the fungal group.

The increase in scientific production on Mycology in the Brazilian context depends on funding measures that encourage research on the group, the establishment of research laboratories related to fungi, and the training of qualified professionals to work with the group. The proposals presented in this research can contribute to the initial training of Biological Sciences, so that future biologists and biology teachers can better

understand the biology of fungi and establish different ways to work with the group. Finally, we point out the potential limitations of the study due to its qualitative nature, the potential extrapolation of the data presented, and the number of universities and textbooks analyzed.

Acknowledgments

This work was supported by a PIBIC scholarship—Rectorate UNESP (No. 7781) granted to the first author. We thank Prof. Dr. Nelson Menolli Junior and Prof. Dr. Beatriz Ceschim for their valuable comments on the original manuscript in the format of the Undergraduate thesis.

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CECIMIG would like to thank CNPq (National Council for Scientific and Technological Development) and FAPEMIG (Research Support Foundation of the State of Minas Gerais) for funding the publication of this article.