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Scientific literacy in the initial training of Biological Sciences teachers: contributions from Edgar Morin's complexity theory

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ABSTRACT

Context: Scientific literacy is a fundamental pillar in the initial training of science teachers. Edgar Morin's complexity theory provides a framework for understanding science education in an integrated, contextualized manner that links various forms of knowledge. **Objectives:** To analyze how scientific literacy (from a complexity perspective) is shown in internship reports developed by pre-service teachers in Biological Sciences during their Supervised Curricular Internship. **Design:** This qualitative, documentary-based study was based on the analysis of reports from supervised curricular internships. The data were analyzed using Discursive Textual Analysis (DTA). **Setting and participants:** Twelve pre-service teachers from the Biological Sciences program at a public university in southern Brazil participated in the study. **Data collection and analysis:** Data were collected from reports on a supervised curricular internship with a focus on internship reports. These plans were analyzed using Discursive Textual Analysis, with categories based on complexity theory, scientific literacy, and initial teacher training. **Results:** The analysis identified five dimensions that express scientific literacy within the internship reports. They reveal potential strengths in the contextualization of teaching, highlighting limitations related to knowledge integration, understanding of the nature of science, and the development of inquiry-based practices. **Conclusions:** The identified dimensions provide an analytical framework for assessing and improving initial teacher training. They offer insights for enhancing curricula, internship practices, and training processes informed by scientific literacy from the perspective of complexity theory.

Keywords: complex thinking; curricular internship; scientific education; lesson planning; internship report.

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Letramento científico na formação inicial de professores de Ciências Biológicas: contribuições da teoria da complexidade de Edgar Morin

RESUMO

Contexto: O letramento científico constitui um eixo fundamental da formação inicial de professores de Ciências e encontra, na teoria da complexidade de Edgar Morin, um referencial para compreender a educação científica de forma integrada, contextualizada e articulada entre diferentes saberes. **Objetivos:** Analisar como o letramento científico, orientado pela perspectiva da complexidade, se expressa nos planejamentos de aula elaborados por licenciandos de Ciências Biológicas durante o Estágio Curricular Supervisionado. **Design:** Pesquisa qualitativa, de natureza documental, fundamentada na análise de relatórios de estágio curricular. Os dados foram analisados por meio da Análise Textual Discursiva (ATD). **Ambiente e participantes:** Participaram da pesquisa doze licenciandos do curso de Ciências Biológicas, de uma universidade pública do sul do Brasil. **Coleta e análise de dados:** Os dados foram coletados em relatórios de Estágio Curricular Supervisionado, com foco nos planejamentos de aula, e interpretados por meio da Análise Textual Discursiva, utilizando categorias fundamentadas na teoria da complexidade, no letramento científico e na formação inicial de professores. **Resultados:** A análise evidenciou cinco dimensões que expressam o letramento científico nos planejamentos de aula, revelando potencialidades relacionadas à contextualização do ensino e limitações quanto à integração dos conhecimentos, à abordagem da natureza da ciência e ao desenvolvimento de práticas investigativas. **Conclusões:** As dimensões identificadas constituem um referencial analítico para investigar e qualificar a formação inicial de professores, oferecendo subsídios para o aprimoramento de currículos, práticas de estágio e processos formativos orientados pelo letramento científico na perspectiva da complexidade.

Palavras-chave: pensamento complexo; estágio curricular; educação científica; planejamento de aula; relatório de estágio.

INTRODUCTION

As scientific, technological, and cultural transformations accelerate, new challenges arise that require individuals to be trained in understanding and applying scientific knowledge in everyday situations. In this context, discussions about scientific literacy (highlighting that educated individuals should be able to apply scientific knowledge to understand and address specific situations in their environment) are becoming increasingly important in education.

In this context, Edgar Morin's contributions offer an innovative perspective for reflecting on science and society. In this study, his insights served as a theoretical framework for engaging with the principles of scientific

literacy, enabling the construction of a more integrated and contextualized understanding of educational processes in initial teacher training. As a sociologist, anthropologist, and philosopher, Morin made significant contributions to complexity theory, promoting a more interconnected view of scientific knowledge and educational practices. He advocated transdisciplinary as a guiding principle, understood as an integration of various disciplines and perspectives to address complex problems effectively. He criticized excessive specialization, fragmentation, and simplification of knowledge, arguing that a full understanding of any phenomenon requires recognizing its interconnections with other fields of knowledge. Thus, he proposed an epistemological approach based on the world's complexity, emphasizing the importance of viewing science, society, and education as interconnected and integrated domains (Morin, 2015a).

Morin (2015a, p. 18) warned against the "*simplifying paradigm*" and "*blind intelligence*" as forms of thought that isolate objects from their contexts and prevent an understanding of the whole: "blind intelligence destroys wholes, and totality isolates all objects from that which surrounds them" (Morin, 2015a, p. 18). For him, complexity should not be seen as a problem to be avoided, but as a challenge to embrace. It requires integrating knowledge and considering political, sociological, psychological, and technological dimensions. He also criticized the tendency to reduce human beings to mere cognitive aspects while neglecting emotions and subjectivities, given that all knowledge is shaped by the human condition (Morin, 2015a, p. 18).

To address the limitations of simplified thinking, Morin (2015a) proposed complex thought, which distinguishes and associates ideas without reducing them, while also recognizing the interconnection, interdependence, and uncertainty that are inherent. In teacher education, this means moving beyond fragmented content, instruction based only on memorization, and the uncritical reproduction of knowledge, thereby fostering a more integrated and reflective approach to organizing the curriculum.

Morin (2001) highlighted that the fragmentation of school knowledge (organized into isolated disciplines) affects the understanding of a "complex and interconnected" world. This segmentation produces a "blind intelligence," incapable of connecting different forms of knowledge and addressing global problems. This can lead to errors, misguided decisions, and increased vulnerability to crises such as pandemics and the technological impacts on agriculture (Morin, 2015b).

Morin (2001) advocated for a "reform of thought" as a prerequisite for true educational reform, emphasizing that the goal of education extends beyond the transmission of content: It must shape "critical and autonomous" individuals capable of connecting different forms of knowledge. He proposed an education oriented toward plurality (valuing "curiosity, doubt, and critical reflection") and aimed at 'cultivating "well-formed minds" rather than merely "full minds". For Morin, education should transform information into knowledge, and knowledge into wisdom, fostering self-development and preparing citizens who are conscious of their "social and ethical" responsibilities. The author warned that superficial curriculum changes (focused solely on the number of subjects or instructional hours) do not resolve the fragmentation of educational thought; the dedication of educators committed to the regeneration/renewal of education is required.

Complexity was defined as *complexus* (that which is woven together), constituted by the "fabric of events, actions, interactions, feedback loops, determinations, and chance occurrences that make up our phenomenal world" (Morin, 2015a, p. 13). The author also emphasized the importance of understanding human complexity and the "educational environment" as "dynamic and interdependent" systems; individual, social, historical, biological, psychological, affective, cultural, and intellectual dimensions interact continuously within them (Morin, 2011).

Based on this theoretical framework, it is possible to rethink scientific literacy more consistently, incorporating didactic-pedagogical elements that enhance educational practices. Santos (2007) understood scientific literacy as a set of competencies that enable citizens to understand everyday phenomena and make decisions regarding science and technology-related issues, at both personal and collective levels. This literacy entails the ability to use scientific knowledge to act responsibly in practical situations, evaluate social, environmental, economic, and ethical impacts, and take a critical stance within spaces of social participation.

Regarding curriculum, the author highlighted the importance of understanding the nature of science, mastering scientific language, and addressing socio-scientific issues; they link science and technology to political, cultural, and social dimensions (Santos, 2007). However, he pointed out recurring limitations in science education (even in contexts with high levels of schooling) evidenced by students' difficulties in understanding fundamental concepts and the social role of science. In the Brazilian context, this problem is exacerbated by the duality of the educational system: curricula geared toward

university admission or basic certification tend to neglect essential aspects of scientific literacy, contributing to student disinterest in scientific subjects (Santos, 2007).

Scientific literacy is essential for the progress of contemporary society, as it expands access to the knowledge needed to improve collective living conditions. According to Motta-Roth (2011), this is a broad process that integrates different fields of knowledge and encompasses four central dimensions: knowledge of science and technology, scientific attitude, understanding and production of scientific texts, and the ability to make informed political decisions, thus contributing to social reflection and the addressing of collective challenges.

Imbernón (2011) highlighted the need to move beyond the traditional model of teacher training centered on content transmission, advocating a redefinition of the profession encompassing pedagogical, scientific, and cultural competencies, as well as a social commitment. For the author, initial teacher training is fundamental to developing reflective and investigative attitudes and building critical and updated professional practice. In this same perspective, Nóvoa (1992) viewed teacher identity as the outcome of interconnected processes of personal, professional, and institutional development, identifying initial training as a key setting for consolidating these dimensions.

Based on the discussions presented, the following research question emerges: in what ways does scientific literacy, in light of complexity theory, manifest itself in the internship reports developed by Biological Sciences pre-service teachers during the Supervised Curricular Internship?

This article presents a document analysis of reports from the Supervised Curricular Internship. The internship was conducted in elementary school education (Science subject) by undergraduate students from a Biological Sciences program at a public university located in the central region of the State of Rio Grande do Sul. The study aimed to analyze how scientific literacy (framed by complexity theory) is reflected in the internship reports created by pre-service teachers during their *practicum*. Therefore, we sought to deepen discussions on teacher education and strengthen more integrated, critical educational practices that address the challenges of science education in the 21st century.

METHODOLOGY

This study used a qualitative approach. According to Minayo (2015), this approach facilitates an understanding of the universe of meanings, values, beliefs, motivations, and attitudes that individuals construct within specific social contexts. This approach is appropriate because it allows for a deeper interpretation of the meanings attributed to lesson planning.

Data collection was conducted through document analysis. This methodological approach uses systematic techniques to examine and interpret documents created in institutional and educational contexts (Sá-Silva *et al*., 2009). This strategy enabled new insights into the phenomena being studied, highlighting how certain concepts and practices are reflected in the analyzed records.

The *corpus* for the documentary research consisted of 12 reports from the Supervised Curricular Internship. These internships were conducted in an elementary school setting (Science classes) by undergraduate students enrolled in a Biological Sciences teacher training program. The internship reports derived from these reports were analyzed to understand how scientific literacy is expressed in the instructional proposals developed during the internships. The analysis also aimed to identify various skills, strategies, and conceptions related to the training of future Science teachers.

This research was submitted to the Research Ethics Committee of *Universidade Franciscana* and approved (Opinion 7.265.647; CAAE 84904924.9.0000.5306), in compliance with current ethical guidelines for research involving human subjects.

Internship reports

The 12 reports analyzed corresponded to all Supervised Curricular Internship reports produced in 2024 and presented the same structural organization. The 12 reports analyzed corresponded to all Supervised Curricular Internship reports produced in 2024. The internships were carried out in different elementary schools, involving observation and teaching activities in Science classes from the 6th to the 9th grade. However, this organization does not follow a standardized model set by the university; it was defined by the homeroom teacher responsible for the internship course. The introduction and presentation sections (characterization of the school and class, internship documentation, activity planning, internship reports, assessment processes, final considerations, and references) were present in all reports.

Pedagogical letters created throughout the training process were also included in the documents.

The reports analyzed contained three pedagogical letters, each of them positioned at different points within the document. These letters served as spaces for reflective and formative writing, where interns shared their perceptions, feelings, expectations, insecurities, learnings, and experiences encountered during their supervised internship. The first letter (found in the report introduction) primarily addressed the interns' initial expectations and perceptions regarding teaching and entering the classroom. The second letter (located before the teaching and internship reports) focused on the experiences developed with the class and the implementation of pedagogical activities within the school context. The third letter (found near the conclusions) adopted a conclusive and reflective tone regarding the formative journey and the knowledge gained throughout the supervised internship.

When profiling a class, pre-service teachers typically used questionnaires to gather insights from students about their interests, preferences, and perceptions regarding the lessons and daily school life. The reports also included the required internship documentation, which should be completed, and the internship reports developed by the pre-service teachers during their teaching *practicum*. It is also worth noting that, before taking charge of the class, pre-service teachers underwent an observation period during which they observed how the regular teacher conducted lessons.

For this research, only the internship reports developed by the pre-service teachers, extracted from the 12 Supervised Curricular Internship reports, were analyzed.

Data Analysis

Discursive Textual Analysis (DTA) was used to process and interpret data. This qualitative analysis method, proposed by Moraes and Galiazzi (2007), facilitates a deep understanding of the meanings conveyed in textual materials. The analytical process involves a continuous cycle of fragmenting and reorganizing the text, allowing new insights to be developed through the dialogue between the researcher and the *corpus*/text being analyzed.

In this study, the *corpus* consisted of internship reports extracted from 12 reports of Supervised Curricular Internships (from a Biological Sciences teacher-training program). The analysis aimed to identify and interpret the meanings attributed to the pedagogical practices proposed by the pre-service teachers.

The Discursive Textual Analysis (DTA) was organized into three stages: unitization (fragmentation of the text), categorization (grouping of units), and construction of metatexts. This process resulted in a comprehensive interpretation and description of data (Moraes & Galiazzi, 2007).

In the context of DTA, analytical categories could be defined *a priori* (established before analyzing the *corpus*) or *a posteriori* (emerging during the interpretive process). In this study, the categories were defined *a priori* (based on complexity theory) within the context of initial teacher education and scientific literacy. The main objective of this study was to analyze how scientific literacy (guided by a complexity perspective) was reflected in the internship reports created by Biological Sciences pre-service teachers during their supervised curricular internship. A total of 46 analytical questions (Figure 1) were formulated based on these frameworks. These questions served as intermediate categories, guiding the reading and examination of the internship reports.

Figure 1

Categories established for Discursive Textual Analysis

FINAL CATEGORIES	INTERMEDIATE CATEGORIES
Conceptual Mastery and the integration of different fields of knowledge	1- Are scientific concepts mastered?
	2- Is scientific knowledge from different fields integrated to foster a broad understanding?
	3- Is prior knowledge considered when building new knowledge?
	4- Are small-scale phenomena connected to global issues?
	5- Are oversimplifications avoided when dealing with scientific concepts?
Contextualization of Knowledge and Connection to Everyday Life	6- Are scientific concepts related to concrete, everyday life situations?
	7- Are scientific phenomena connected to practices of care, preservation, and socio-environmental responsibility?
	8- Are students' experiences or observations used to introduce scientific concepts?
	9- Are examples of how science can be applied given to solve community problems?
	10- Are our origins, dimensions, and relationships with the planet taught?

	11- Is science linked to preservation, empathy, and care for life?
	12- Are local, regional, and global perspectives related when scientific phenomena are explained?
	13- Is the understanding of how everyday decisions involve scientific knowledge promoted?
	14- Are the implications of scientific knowledge for individual and collective quality of life discussed?
Nature of Science, Ethics, and Epistemological Awareness	15- Is the way scientific knowledge is produced and transformed over time emphasized?
	16- Are scientific validation criteria (such as evidence, peer review, scientific consensus, errors, and revisions) discussed over time?
	17- Is science presented as a human, historical, and social construct, rather than as neutral or absolute knowledge?
	18- Are ethical discussions related to scientific knowledge encouraged?
	19- Are historical scientific errors that resulted in tragic consequences analyzed?
	20- Is scientific knowledge clearly distinguished from opinions, beliefs, or common sense?
	21- Is there encouragement for critical analysis of scientific information sources in the media?
	22- Is the role of science in the contemporary world examined?
	23- Are efforts made to help individuals make informed decisions, critically assess *fake news*, and address controversies and science-denialist rhetoric using a scientific basis?
Inquiry-Based Learning and Problem-Solving-Based Teaching	24- Is science used to solve community problems?
	25- Are scientific criteria followed to solve problems?
	26- Are research projects proposed using data collection, organization, and systematic analysis?
	27- Is the oral and written scientific communication of results encouraged?
	28- Is the formulation of investigable questions by the students themselves encouraged?
	29- Is information questioned, and are debates and argumentation promoted?
	30- Do practical activities have an investigative purpose?
	31- Are autonomy and self-organization encouraged?
	32- Are dialogue and debate encouraged?
	33- Are innovative methodologies used?

Pedagogical and Human Dimensions and the Dynamics of Teaching Practice	34- Are affective, social, and cultural dimensions integrated?
	35- Are emotions, the class's pace, and human interactions considered?
	36- Is the ability to adapt practice in the face of the unexpected shown?
	37- Are questioning, investigation, and curiosity encouraged?
	38- Is sensitivity to students' individual needs demonstrated? Are empathy and mutual respect fostered during classroom interactions?
	39- Is there observation of and appropriate response to unexpected situations?
	40- Is scientific language adapted to the school context?
	41- Are technological resources used?
	42- Are exchanges between students promoted?
	43- Is reflection on the learning process itself encouraged?
	44- Are lessons planned according to the context, class, location, and/or needs?
	45- Is student curiosity stimulated? Is there room for questions?
	46- Are uncertainties and errors analyzed to foster learning?

The 46 intermediate categories were organized by comparing and grouping elements with similar meanings, leading to form five final categories. During this categorization process, units of meaning or Units of Analysis (UA), understood as text segments that are meaningful in relation to the research objectives, were systematized into analytical categories, as proposed by (Moraes & Galiazzi, 2007, p. 75).

In the final stage, the new emerging intermediate categories were captured through metatext elaboration and structured in the five final categories: 1) Conceptual Mastery and Integration of Different Knowledge Areas; 2) Contextualizing Knowledge and its Relationship to Daily Life; 3) Nature of Science, Ethics and Epistemological Consciousness; 4) Inquiry-Based Learning and Teaching from Problem Solving; and 5) Pedagogical and Human Dimensions and Dynamics of Teaching Practice.

RESULTS AND ANALYSIS

Conceptual mastery and integration of different knowledge areas

In teaching practice, mastering scientific concepts is important, but knowing how to relate them to other knowledge areas is equally necessary. This approach helps avoid oversimplifications and favors a broader and more

meaningful understanding of phenomena. This also involves considering and valuing students' prior knowledge, integrating it into the construction of new knowledge (with greater engagement and participation from everyone) and welcoming the coexistence of distinct (or even contradictory) ideas, thus contributing to developing a reflective stance towards scientific knowledge. In the study by Teles *et al*. (2025), 150 teachers in initial and continuing training recognized the importance of interdisciplinarity in science education, highlighting its contribution to critical thinking, scientific reasoning, problem-solving, and integrated understanding of knowledge, making learning more motivating.

In the internship reports analyzed, the mastery of scientific concepts emerges in the pre-service teachers' reflections when they examine their own practices, especially when they question themselves about "what can be improved" in their internship reports. This domain is frequently associated with the perceived need to "study the content to explain it" and to "know the concepts better to answer students' questions". These records reveal an initial understanding that knowing scientific content is a fundamental requirement for the quality of pedagogical actions in the classroom. As García (1999) pointed out, insufficient mastery of the subject matter can lead teachers to make mistakes, compromising both what they teach and how they teach it.

However, weaknesses typical of first professional experiences sometimes arise, often intensified by nervousness, as one student expressed: "I answered *I don't know* a lot, and that disappointed me". This type of report highlights the insecurity that can arise from classroom demands and the expectations associated with teaching. However, these situations should not be seen as a cause for concern, but as a natural part of learning in initial training. Recognizing one's own limitations and seeking to expand one's conceptual understanding shows an important reflection and professional development. This indicates that the pre-service teachers are gradually building their scientific knowledge and pedagogical practice, strengthening their teaching identity through the experiences gained during their internship.

When analyzing the evidence regarding the integration of scientific knowledge from different areas, indications of conceptual fragmentation and content simplification were identified. This is often associated with the need to "summarize as much as possible to save time," "cover the content of the plan", or even the perception that "with practice, I understood that each topic should be presented in summary on the board, with diagrams, drawings, and mind maps [...] due to [...] the speed at which most students took notes". These

aspects may be related to the dynamics present in the school context. They are characterized by accelerated content completion, the use of textbook-based systems, and internal and external assessments linked to performance in standardized evaluations and large-scale exams. This scenario tends to favor more content-based and fragmented approaches, limiting articulation among different knowledge areas and hindering a more integrated understanding of scientific phenomena.

In some situations (when the use of slides was observed), the concepts were also presented in a direct and simplified manner. However, it is not possible to clearly state whether such choices stem from weaknesses in conceptual integration or whether they are primarily related to the need to follow a pre-established plan to cover the expected content (especially in the context of the internship, in which pre-service teachers often work guided by the supervising professor's plan). Thus, for scientific literacy to develop in a critical and emancipatory way, teaching and learning practices need to be active, incorporating interdisciplinarity, uncertainty, and the complexity of real life (Valladares, 2021).

The way students' prior knowledge appears recurrently in the internship reports analyzed, generally used as an initial probing strategy, through questions aimed at "identifying what students already know about the content" (...) "asking what they know about the subject". However, it is rarely explained how student responses influence teaching decisions of pre-service teachers. Thus, prior knowledge activation tends to assume a predominantly introductory or motivational function. Although pre-service teachers show concern about "verifying students' prior knowledge", evidence that this information is used to "reorganize the teaching path, adjust strategies, or deepen concepts throughout the lessons" is rare. In general, gathering initial concepts does not seem to lead to pedagogical actions that would continue classroom discussions. A more consistent example of this approach appears when the teacher proposes: "to test students' prior knowledge, ask the class to name the organs they know and write them on the board, then group them by system". In this case, it was observed that prior knowledge is not only searched for but also used as a starting point for conceptual organization of the content.

Contextualizing Knowledge and its Relationship to Daily Life

For scientific knowledge to be recognized as part of everyday decisions and actions, teachers must relate the content to real-life situations in students' lives and actual social challenges such as health, environmental issues, sustainability, and technology. This involves integrating various dimensions to

explain different phenomena. Thus (using the example given by Durigon *et al*., 2023), when working on the topic of dengue fever, teachers can relate the biological content about the *Aedes aegypti* mosquito and the associated virus to everyday environmental factors. These factors might include sanitation, proper waste disposal, urbanization and climate change, economic impacts of the disease such as public spending on hospitalizations, campaigns and surveillance. Additionally, teachers can cover the responsibilities of different levels of government regarding prevention policies. The approach may include how vaccines are developed, evaluated (from basic research to clinical trials), and approved by bodies such as Butantan, Fiocruz, and Anvisa, highlighting the importance of investment in research and the work of scientists. Control technologies (such as genetically modified mosquitoes and the role of scientific communication in combating *fake news*) can also be addressed. By involving students in analyzing epidemiological data and proposing actions for the community, teachers highlight dengue as a phenomenon that can link science, politics, economics, technology, and culture, fostering a critical and contextualized understanding that encourages student engagement.

This perspective engages with the notion of relevant knowledge presented by Morin (2011). It presupposes considering the context, the global and the multidimensional environment while criticizing modes of thought that fragment knowledge, disconnect objects from their contexts, and limit the understanding of the whole, producing what the author calls "blind intelligence", marked by the destruction of sets and the separation of objects from everything that surrounds them. From this same perspective, García (1999) highlighted that teachers must know the context in which they work (including socioeconomic and cultural characteristics and the students' expectations) to adapt teaching to the school's real needs. He also argued that teacher training should develop skills that allow teachers to understand the complexity of teaching in culturally diverse contexts, promoting reflection, tolerance, and respect for individual and collective differences.

In terms of contextualizing scientific knowledge and its relevance to daily life, an analysis of internship reports revealed that this practice is primarily associated with health topics. There is a notable tendency to connect scientific content to issues related to care, prevention, and well-being. This emphasis was manifested in proposals that link biological concepts to concrete practices (such as "discussion about condom use and access to public health services"; "cardiovascular diseases and prevention"; "actions focused on sex education and public health"; "the evolutionary leap of SARS-CoV-2") as well as strategies based on "case studies involving the main diseases caused by

protozoa. These teaching choices show consistency with the pedagogical intent explicitly stated in the reports, such as when the student teacher affirmed that he/she "always sought to relate the content to the students' daily lives, maintaining a continuous dialogue and considering their prior knowledge, in addition to trying to bring curiosities that arouse interest and information of public utility to the classes, especially related to health". Despite the dominance of this approach, other forms of contextualization also arise, although less frequently. For example, when introducing the topic of bacterial reproduction, students might be invited to taste yogurt, sparking a discussion about the significance of bacteria and their applications in industry. Another instance could involve giving away a candy made from algae to highlight the usefulness of algae in industrial applications. These examples reveal efforts to expand the connection between science and society.

The recurrence of the health theme (as the main way of contextualizing scientific knowledge) may be related to the pedagogical security perceived by undergraduate students, who resort to examples already consolidated in school materials. Furthermore, this predominance of contextualization may also be associated with the content planned for the grades/years in which the internships were conducted, since health-related topics frequently appear in the curriculum documents for the Science subject at these stages of Basic Education. This emphasis on health is close to the practical category defined by Shen (1975), who involved the use of scientific knowledge to deal with everyday problems related to health and nutrition. However, teachers can also explore the other dimensions of scientific literacy proposed by the author when working with other content and themes throughout Basic Education, although they may be less frequent in the plans analyzed. Among these dimensions, we highlight the civic category (related to understanding social and political issues linked to science and technology) and the cultural category (associated with an interest in science as part of culture and intellectual life). Based on these dimensions, themes such as technology, energy, environment, sustainability, and public policies can contribute to broadening the contextualization of teaching, thus favoring a more comprehensive understanding of science.

The connection between small-scale phenomena and global problems also has the potential to be developed, as exemplified in the case of the "practical activity in which students observed bacterial growth"; in this example, proposing the cultivation of bacteria subjected to different temperatures or substrates would be possible, allowing them to perceive how small environmental variations influence the rate of microbial reproduction. Based on this observation, the teacher could lead a discussion about microbial control

and the consequences of interrupting antibiotic treatments, introducing the concept of selection of resistant bacteria (even at the microscopic level) and connecting this phenomenon to the global problem of antimicrobial resistance (recognized by the WHO as one of the greatest threats to global public health). By creating links between the local and global environments, teaching practices align with the perspective advocated by Morin. He emphasized the need to understand phenomena within their broader contexts, warning that "[...] the more planetary the problems become, the more unthinkable they become". An intelligence that cannot perceive context and the complexity of global issues becomes blind, unconscious, and irresponsible" (Morin, 2001, p. 15).

This understanding is also a central element of scientific literacy (as proposed by Santos, 2007), by linking the understanding of everyday phenomena to the ability to make informed decisions about science and technology issues, in both personal and collective contexts. Thus, scientifically literate people can interpret package inserts, prepare dilutions, adopt basic health care practices, use technologies, and evaluate information to exercise their rights. The author also emphasized that this literacy involves ethical and responsible decisions in daily life, considering not only the effectiveness of products, but also their environmental, social, and economic impacts and the production conditions.

Nature of Science, Ethics and Epistemological Consciousness

The approach to the nature of Science, Ethics, and Epistemological Consciousness involves understanding how scientific knowledge is produced, validated, and transformed over time, recognizing its historical, social, and human character. In the classroom, teachers can work with science as a human, historical, and social construct, marked by uncertainties, errors, revisions, and provisional consensus. This involves discussing criteria for scientific validation, differentiating science from opinions, beliefs, and pseudoscience, analyzing scientific information disseminated in the media, as well as problematizing ethical aspects and the role of science in the contemporary world, preparing students to make informed decisions using science in their daily lives.

The reports analyzed indicate that the Nature of Science approach in planning focuses primarily on demonstrating "doing science". This appears in proposals such as: “students will be able to observe a colony of bacteria (kefir) and understand the speed of bacterial development from the growth curve represented in the textbook,” in activities that suggest “looking for a living being in the schoolyard, taking a photograph or drawing it”, as well as in practices such as “DNA extraction [...] mixing water with salt and detergent,

[...] crushing a banana [...] observing the clump that forms on the surface: it's DNA; [...] explain to the students the function of some ingredients [...], highlight that in this cluster that is floating [...] there is the necessary information for the formation of the fruit [...]". Although hands-on experience in DNA extraction has investigative potential, it appears in reports as a mainly demonstrative activity. To make it investigative, the teacher can replace the step-by-step guide with another situation that encourages students to think about how to make DNA visible using simple materials, presenting only the general function of the reagents, without handing over the protocol. From this, students formulate hypotheses, compare ingredients, test different concentrations, explore other fruits, or investigate the effects of temperature and resting time. Based on these hypotheses, each group plans its own procedure, records observations, and discusses why some combinations produce better results. Thus, the practice ceases to be merely demonstrative and becomes a guided investigation, bringing students closer to the real processes of scientific knowledge production and strengthening their critical thinking.

Lesson planning involving the development of hypotheses was also observed, such as the proposal to "ask them to assemble the life cycles before explanation. This led them to formulate hypotheses about the order of events, prompting them to construct initial explanations on their own. In addition, moments dedicated to discussion and the collective construction of knowledge were observed and exemplified by initiatives such as "organizing students into groups to discuss simplified clinical cases related to the viral diseases studied".

On the other hand, discussions about how scientific knowledge is validated (including criteria such as evidence, peer review, and scientific consensus) and aspects of the historical, human, and social nature of science have remained largely unexplored or absent. Reflections on the limits of scientific knowledge, its errors and revisions over time, the ethical implications and consequences of historical errors in science, as well as the differentiation between scientific knowledge, beliefs, opinions, common sense, and pseudoscience also appear in a limited way. The limited critical analysis of scientific information disseminated in the media and the confrontation of *fake news,* denialist discourses, and scientific controversies can be added to this. These aspects have important potential for teaching, as they can broaden the understanding of science beyond experimental practice, strengthening critical epistemological awareness and preparing students for informed decisions in the contemporary world.

Although the internship reports analyzed reveal the interns' concern with proposing practical classes, many of these activities could be oriented towards an investigative character, broadening the approach to how scientific knowledge is constructed and validated, including criteria of evidence, peer review, and consensus building. Reflections on the historical, human, and social character of science, its limits, errors, and revisions over time, as well as discussions of distinctions between scientific knowledge, beliefs, opinions, common sense, and pseudoscience could also be included. Incorporating these elements represents a promising avenue for future teaching practices, as they can deepen the understanding of science beyond mere experimentation and promote a more critical, ethical, and epistemologically aware scientific education.

This need to broaden students' understanding of the nature of science is close to the concept of scientific literacy proposed by Shamos (1995). For him, scientific literacy involves a theoretical and epistemological understanding of science, including its investigative processes, the role of experimentation, and the development of scientific models. For this author, being literate does not just mean knowing scientific vocabulary, but being able to dialogue and discuss science in a coherent and meaningful way in non-technical contexts. This reinforces the importance of addressing dimensions that have not yet been adequately considered in the plans analyzed.

Inquiry-Based Learning and Teaching through Problem Solving

When we talk about problem-solving, it is important to understand what characterizes a situation as a problem. Among various definitions found in the literature, we have selected one that contributes to a better understanding of what defines it: "a situation can only be seen as a problem to the extent that it is recognized as such, and we have no automatic procedures that allow us to solve it more or less immediately, without somehow requiring a process of reflection or decision-making about the sequence of steps to be followed" (Echeverría & Pozo, 1998, p. 16).

Problem-solving has been addressed by different authors, assuming terminological variations that reflect distinct theoretical perspectives in the field of mathematics education and science teaching, both in national and international production. In the Brazilian context, expressions such as "problem-solving methodology" (Dante, 2010) and "teaching-learning-assessment through problem-solving" (Allevato & Onuchic, 2014) are found. In the field of science education, expressions such as "inquiry-based teaching"

(Carvalho, 2013), “three pedagogical moments” (Delizoicov *et al*., 2011), and “problematization” from a Freirean perspective (Freire, 1996) were highlighted.

In the international context, the approach known as Problem-Based Learning (Barrows, 1986) was found. The work developed by Cazzola (2007) was highlighted using this approach, especially in the Italian context. They discussed the organization of mathematics laboratories and investigative environments, emphasizing the active participation of students, the collective construction of knowledge, and the mediating role of teachers in the development of activities.

These different terminologies show that there are elements that permeate the problem-solving approach (such as active student participation, investigation, problematization, hypothesis formulation, argumentation, validation, dialogue, autonomy, as well as teacher mediation, application, and relationship with the context), although the terms used vary. These aspects indicate that students are seen as active subjects in the construction of knowledge, assuming a central role in the teaching and learning processes.

In the Italian context, Cazzola (2007) has contributed to broadening discussions about teaching from a problem-solving perspective, as an approach capable of fostering more investigative and participatory learning. In his studies, the problem is understood as an organizing axis in the teaching and learning processes, enabling students to assume an active stance towards knowledge through investigation, formulation of strategies, reflection, and collective construction of solutions. Although his studies are linked to Mathematics Education, the principles present in their discussions engage contemporary perspectives on Science teaching and scientific literacy, especially valuing problem-solving, argumentation, and student participation in the construction of knowledge.

The solving approach has been understood as a teaching perspective that organizes learning based on challenging situations that can mobilize investigation, reflection, argumentation, and decision-making. From this perspective, students are encouraged to develop strategies, formulate hypotheses, discuss possibilities, and build pathways to solve problems, taking an active stance towards knowledge. Discussions developed with this approach emphasize student-centered pedagogical practices, in which learning occurs through the analysis, discussion, and collective resolution of problematic situations, especially in contexts that favor exploration, dialogue, and the active construction of knowledge (Cazzola, 2007).

This emphasis on problems as a teaching tool was systematized in what is called Problem-Based Learning (PBL), understood as a constructivist approach focused on the analysis, resolution, and discussion of significant problems (as opposed to traditional teaching models centered on the mechanical transmission of content). From this perspective, pedagogical work starts with problems considered stimulating and challenging, developed collectively through the mediation of teachers, requiring time for investigation, discussion, and socialization of the different strategies constructed by students. Furthermore, problem-based learning can be applied in different areas of knowledge and educational levels, based on the understanding that problems act as stimuli for thinking and constructing knowledge (Cazzola, 2007).

Based on authors in the areas of Education and Didactics of Mathematics, Cazzola (2007) highlighted that teachers in problem-based learning do not act solely as transmitters of content, but assume roles related to the development of materials, observation of students, and implementation of appropriate pedagogical interventions throughout the activities. From this perspective, students are encouraged to build their own strategies and develop greater autonomy, while teachers act as mediators in the learning process. Cazzola also emphasized that the effectiveness of this approach depends on proposing problems that are sufficiently challenging, interesting, and meaningful, in addition to the teacher understanding the students' knowledge, difficulties, and ways of thinking. According to Cazzola (2007) activities based on problem-based learning can favor the development of situation analysis, selection of relevant information, elaboration and reformulation of strategies, flexible construction of knowledge, metacognitive skills, collaboration among colleagues, and motivation for learning.

In the context of this study, this perspective showed/proved to be especially relevant to scientific literacy, as it allows students to experience stages like those present in scientific investigation. Throughout activities, students are encouraged to formulate hypotheses, analyze situations, develop strategies, revise interpretations, discuss possibilities, and communicate the results produced collectively. Thus, teaching is no longer restricted to the reproduction of information, but rather favors investigative, reflective, and participatory experiences, bringing students closer to practices related to the construction of scientific knowledge.

The analyzed excerpts show that Problem-Based Learning and Inquiry-Based Learning are present in the internship reports (although partially in many cases), considering some of their stages. Proposals that value scientific

communication (such as the use of systematic records) were observed. This was exemplified in "The Logbook is a small block... used by students for note taking", as well as assessments focused on report production, such as "the assessment was performed through an experimental report". Evidence of investigative practices also emerged when students were invited to develop hypotheses and test explanations (as in the excerpts "divided into groups, the students needed to create hypotheses to explain the emergence of living beings in unlikely places" and "the group members needed to develop a hypothesis to explain this event and an experiment to try to confirm their hypothesis").

Although the analyzed excerpts show important stages of investigative practices, there is still great potential to expand this approach, strengthening proposals that use science to solve community problems and developing activities better guided by scientific criteria. Planning can also advance the implementation of projects that include data collection and analysis over time. Expanding spaces for dialogue, debate, and oral scientific communication can make the investigative approach more integrated and strengthen students' protagonism in the construction of knowledge (in addition to encouraging students to formulate investigable questions and stimulating evidence-based argumentation, informed decision-making, and student autonomy).

Within the scope of the Adolescent School Program, the *Scientific Literacy Club* (*Curriculum Innovation Notebook, CIN*; prepared by the Ministry of Education; Brazil, 2022) is a guiding material aimed at implementing educational spaces that promote the development of scientific literacy in the final years of elementary school. The proposal was based on investigative teaching perspectives, valuing student protagonism, problem-solving, and the active construction of scientific knowledge. Among the guidelines presented in the material, we highlight the following: formulating investigative questions and hypotheses based on everyday situations, planning and conducting experiments, collecting, organizing, and critically analyzing data, as well as developing solutions and innovative actions related to the problems investigated. The document mentioned above also emphasizes the development of skills related to argumentation, decision-making, and the use of scientific knowledge to understand and solve problems present in social and everyday contexts. Furthermore, this material provides different didactic sequences organized from a problem-solving and inquiry-based learning perspective. They can be adapted by teachers according to the pedagogical objectives and the class context, favoring more participatory, reflective, and contextualized practices.

Pedagogical and Human Dimensions, and Dynamics of Teaching Practice

The pedagogical and human dimensions, and dynamics of teaching practice relate to the teacher's ability to conduct instruction sensitively and flexibly, adapting to the students' diversity and considering not only scientific content but also effective, social, and cultural aspects present in the classroom. This involves using diverse methodologies and resources, including innovative strategies; adapting scientific language to the school context and the students' needs; to cater to human rhythms, emotions, and interactions to encourage curiosity, questioning, investigation, and the expression of ideas, promoting intellectual autonomy, authorship, and exchanges among students. This also includes the ability to deal with uncertainties, observe unexpected situations, adjust routes and reorganize planning based on the results of pedagogical actions, analyze errors and unforeseen events as learning opportunities, and ensure that classes are planned in dialogue with the contexts of the class, location, and specific educational needs.

The analysis of reports revealed different aspects of the pedagogical, human, and dynamic dimensions of teaching practice. Phrases such as "looking at a cell slide under a real microscope for the first time" or "I chose figures of the characters from the animation *Cells at Work!*" illustrate the use of innovative methodologies and didactic representations that bring scientific content closer to the students' world. When a student teacher states that it is "impossible to forget my first class on the last day; while they begged me to continue, I gave each one souvenirs I had made myself [...]", the building of bonds, care, and the valuing of human relationships in the educational process can be observed. Sensitivity to differences also appears in records such as "the special student in the class felt excluded when she could not find a partner… I need to think of ways to include her better" and "I need to take into account that they do not do the activities quickly; corrections also take a long time", which show attention to learning rhythms and needs. Reflections such as "thinking about ways to encourage thinking and not seeking everything in a fixed way" and the question "how do our thoughts work?" indicate an openness to deepening discussions about the learning process itself.

Other records show the diversification of teaching strategies, such as "reviewing for a test using Kahoot," and the ability to adapt to unforeseen events, as in the accounts "I planned very little and had time left over" and "I adapted the way I did the activity in the book (an individual sheet that would serve as reference material for the test) and it worked much better". In passages

such as "students should debate in their groups," the encouragement of dialogue and collaborative work is observed.

Despite the identified indications, there is still potential to further explore this dimension (especially regarding lesson planning based on the characteristics of the neighborhood, the class, and the students' needs), recognizing that a minimally structured plan can and should be adapted during the process. A space for exploring uncertainties was also observed, treating errors and unforeseen events as formative opportunities and stimulating reflection on one's own learning. These aspects help to consolidate a more sensitive and flexible teaching practice, aligned with the human dimensions of teaching and learning.

Imbernón (2006) argued that educational institutions should go beyond teaching content, also addressing the complexity of educating citizens in their multiple dimensions. Along the same line, García (1999) highlighted that knowing the socioeconomic and cultural context of the school and its students is essential knowledge for teaching; it is acquired primarily through the interactions experienced in teaching practices and internships.

Morin (2011) argued that teaching about the human condition is essential, valuing both what unites us and the diversity that constitutes us: to foster earthly identity through planetary awareness and the strengthening of ties with the planet, to understand and confront uncertainties as inherent elements of the human experience, and to promote mutual understanding as a basis for developing intellectual and moral solidarity.

Morin (2011) argued that education should form "well-formed minds", capable of solving problems, questioning, and reformulating their own thinking. According to this author, transforming information into knowledge and knowledge into wisdom is the responsibility of the school, by stimulating curiosity, doubt, and critical reflection. He further emphasized that all knowledge is interpretive and subject to error; this makes it essential to develop critical rationality, the capacity for self-criticism and self-observation, as well as preparing students to deal with uncertainty as a constitutive part of human experience, recognizing the very provisional and dynamic nature of knowledge.

When considering education in the future, Morin (2011) emphasized the need to focus on the study of human complexity. This suggests that educational practices will be better understood by recognizing the diversity of dimensions that make up human nature; it is complex and encompasses individual, social, historical, biological, psychological, affective, poetic,

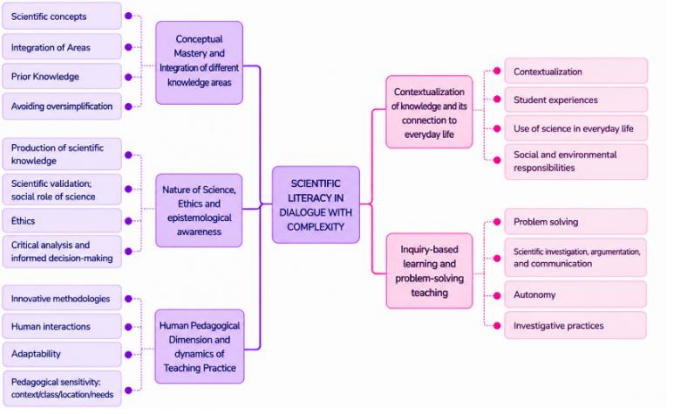
intellectual, and cultural dimensions. It is also important to recognize the complexity of the educational environment, which consists of a network of interconnections between situations, processes, phenomena, and realities in constant interaction. Morin (2015b) said that we can teach how to reconnect knowledge to life and develop autonomy, as methods for better guiding the mind and dealing with everyday problems.

It is necessary to promote an education geared towards responsible social action in a way that is close to the students' reality: stimulating debate and the collective construction of solutions, preparing citizens to critically question scientific and technological developments, and encouraging changes in attitude. It is up to science teachers to integrate environmental, cultural, economic, political and ethical discussions into classes, while also involving students in concrete social actions (Santos, 2007).

Initial teacher training was understood by Nóvoa (1992) as a privileged period of study that not only characterizes the training of future teachers but is also the basis for their professional development. Imbernón (2011) added that this stage provides the necessary foundations for teachers to develop pedagogical knowledge essential to practice. This author argued that initial training should promote valid knowledge and encourage interactive and dialectical attitudes, valuing continuous updating and the creation of strategies for intervention, cooperation, analysis, reflection, and investigation to consolidate a more rigorous and critical professional style. Figure 2 summarizes the main ideas that emerged from the five dimensions analyzed in the light of DTA.

Figure 2

Synthesis of the dimensions of scientific literacy in initial teacher training



This figure and the intermediate categories (Figure 1) that guided the analysis are analytical-formative instruments with potential for future research and guidance in initial teacher training. They resulted from the systematization of various theoretical frameworks, especially those from the field of scientific literacy and Edgar Morin's perspective on complexity in the context of initial teacher training. They allow not only the analysis of internship reports and educational practices, but also guide reflective processes in initial teacher training, contributing to the identification of potentialities, gaps and challenges in the development of scientific literacy aligned with the complexity of science teaching.

FINAL CONSIDERATIONS

This study analyzed, in light of Edgar Morin's Complexity theory, the internship reports in the initial training of Biological Sciences teachers, highlighting five central dimensions for developing scientific literacy: 1) Conceptual Mastery and Integration of Different Areas of Knowledge; 2) Contextualizing Knowledge and its Relationship to Daily Life; 3) Nature of Science, Ethics and Epistemological Consciousness; 4) Inquiry-Based Learning and Problem-Solving Teaching; 5) Pedagogical and Human Dimensions and Dynamics of Teaching Practice.

The questions that guided the above analysis are a methodological tool for the study and a reference for future research, integrating the dimensions of scientific literacy and complexity in initial teacher training. At the same time, they point to possible improvements in the initial training of Biological Sciences teachers, while they make visible not only the elements present in internship reports, but also their potential, gaps, and challenges, offering support for the revision of curricula, internship practices, and training processes aligned with the demands of current science education.

To progress towards a more scientifically literate society, it is important to organize teaching practices based on a thematic approach of the cultural, social, and historical dimensions and those inherent to the scientific process itself, articulating broad themes such as health, environment, sustainability, technology, energy, science and society; these themes can integrate knowledge, promote contextualization, and foster a critical and meaningful scientific education.

In initial teacher training, promoting scientific literacy is essential; it enables these future professionals to understand science as a part of everyday life, recognizing its role in their own lives and developing conditions to apply

this understanding to their teaching practices from the beginning of their professional careers.

Overall, the reports indicated that the scientific literacy of the interns is still in construction, requiring a broader, integrated, and intentional approach. The need to promote more pedagogical practices that reconnect knowledge, integrate science and society, deepen understanding of the nature of science, and embrace uncertainty as an inherent part of scientific knowledge was highlighted. These practices should prepare future teachers to deal with the complexities of the contemporary world and effectively promote student learning. In this sense, we reinforce the importance of teacher training that goes beyond the technical and instrumental domains, oriented towards a critical, ethical, contextual and human understanding of science and contributing to the formation of reflective, autonomous and socially responsible citizens.

AUTHORS' CONTRIBUTIONS STATEMENTS

MD, GS, CC e TSCD conceived the presented idea. MD developed the theory. MD adapted the methodology to this context, created the models, performed the activities, and collected the data. MD analysed the data. All authors actively participated in the discussion of the results, reviewed and approved the final version of the work.

DATA AVAILABILITY STATEMENT

The data supporting the results of this study may be made available by the author MD upon reasonable request.

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