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Paradigms at Stake in Science Experiments in Extension Activities

Paradigmas Envolvidos na Experimentação em Ciências nas Ações Extensionistas

Paradigmas Implicados en la Experimentación en Ciencia en Acciones de Extensión

Daiane Rattmann Magalhães Pirez, Rafaele Rodrigues de Araujo, and Valmir Heckler

Abstract

This study investigated, through a Literature Review, how experiments in university extension programs are addressed in Brazilian research on Science Education (2001–2023) based on publications retrieved from the Oasisbr portal. The qualitative analysis, relying on Discursive Textual Analysis, highlighted the prevalence of conceptions associated with a simplistic paradigm, centered on fixed scripts and the verification of theories. However, it also showcased transition movements towards constructivist perspectives, walking hand in hand with the complexity paradigm—in such perspectives experimentation now emphasizes problematization as well as dialogue and the active role of students.

Keywords: experimentation, extension projects, Science Education

Resumo

Este estudo investigou, por meio de um Estado da Questão, como a experimentação em ações de extensão é abordada na produção brasileira em Educação em Ciências (2001–2023), a partir de publicações recuperadas no portal Oasisbr. A análise qualitativa, fundamentada na Análise Textual Discursiva, evidenciou a predominância de concepções associadas a um paradigma simplificador, centrado em roteiros fechados e na comprovação de teorias, mas também revelou movimentos de transição em direção a perspectivas construtivistas, em diálogo com o paradigma da complexidade, nas quais a experimentação passa a valorizar a problematização, o diálogo e o papel ativo dos estudantes.

Palavras-chave: experimentação, projetos de extensão, Educação em Ciências

Resumen

Este estudio investigó, mediante una revisión del estado del arte, cómo se aborda la experimentación en las actividades de extensión en la producción brasileña de educación científica (2001-2023), a partir de publicaciones recuperadas del portal Oasisbr. El análisis cualitativo, basado en el Análisis Discursivo Textual, reveló el predominio de concepciones asociadas a un paradigma simplificador, centrado en guiones cerrados y la verificación de teorías, pero también reveló movimientos de transición hacia perspectivas constructivistas, en diálogo con el paradigma de la complejidad, en el que la experimentación comienza a valorar la problematización, el diálogo y el rol activo de los estudiantes.

Palabras clave: experimentación, proyectos de extension, Educación Científica

Introduction

When it comes to Science teaching, experimentation[1] may encompass various types of activities carried out in school settings, also differing in terms of the form of interaction, the degree of structure, and the pedagogical objectives (Araújo & Abib, 2003; Mori & Curvelo, 2017). It can take on a demonstrative character when led by the teacher, or a manipulative one when it involves direct student participation and can range from structured lesson plans designed to test theories to more open-ended investigative activities (Rosito, 2003; Carvalho, 2010). Thus, it is teachers' pedagogical and epistemological conceptions of the teaching and learning process that determine how these activities will be conducted in school laboratories (Borges, 2003; Silva et al., 2012).

It is worth noting that recent trends have shifted the analytical focus from experimental activities to more contemporary areas such as teacher training and research-based experimentation, specific curriculum proposals, the use of simulators, remote experimentation, and educational robotics In these studies, experimentation is not treated as the central focus of analysis, but rather as an element linked to other aspects of Science Education. Therefore, we emphasize that the references to experimentation cited in this study, although dating from before the last decade, constitute well-established theoretical frameworks in the discussion regarding the organization and modes of development of experimental activities in school laboratories, and are revisited here as a basis for examining their reinterpretations in the context of extension activities.

Drawing on Becker (2001), we have taken three epistemological approaches as our reference points: empiricism, a priori theory, and constructivism. In empiricism, experimentation tends to be viewed as the mere manipulation of variables to test theories, linked to closed-ended demonstrations and lesson plans that reinforce a vision of definitive knowledge (Rosito, 2003; Silva et al., 2012). Constructivism, on the other hand, emphasizes subject–object interaction and problem-solving, recognizing the role of prior knowledge in the construction of scientific knowledge (Rosito, 2003; Moraes, 2003).

As a result, it is common for experimental activities in science education to be designed based on different pedagogical and epistemological paradigms and models. Such distinction is key in this study, as experimentation is understood as a practice that could either reinforce the fragmentation of knowledge or foster the integration necessary for understanding complex phenomena. We relate the concepts of experimentation to the "simplifying" and "complex" paradigms proposed by Morin (2011). The simplifying paradigm fragments knowledge and tends to guide experimental practices focused on confirming theories through demonstrations and predetermined protocols, whereas the complex paradigm emphasizes contextualization, uncertainty, and critical inquiry, aligning with constructivist approaches that value students' active participation.

1 In the present study, we opted for using the terms "experimentation" and "experiential activities" in order to encompass a wider set of works analyzed. Nevertheless, as Mori and Curvelo (2017) as well as Malheiro (2016) posit, such terms might not be regarded as synonyms, once they differ from each other depending on either the degree of systematization or the methodological intention underlying teaching activities.

It should be noted that, in this study, constructivism is not regarded as equivalent to the complexity paradigm, nor as an automatic extension of research approaches. Indeed, both share a critical view of rote learning, but their perspectives differ. Thus, constructivism is regarded as conscious adoption of a paradigm encompassing the reality as a process being continuously developed, leading to the acknowledgment of its incompleteness, unfinishedness as well as continuous (re)construction of both subject and knowledge (Moraes, 2003), while complexity is mobilized, especially in the analysis carried out, as an epistemological framework to interpret the tensions, constraints, and shifts in experimenting conceptions pervading the literature, especially in the realm of university extension.

Although the debate over the objectives of experimental activities is well established in science education, its analysis in specific educational contexts still requires further exploration. Among these contexts, extension activities stand out, driven by the policy of integrating extension into the curriculum established by Law No. 13,005/2014 (PNE 2014–2024), which incorporates extension into undergraduate curricula. In this context, extension activities emerge as potential venues for initial training, characterized by tensions between different pedagogical paradigms and reflecting distinct epistemological perspectives in experimental activities. Thus, by analyzing the experimental activities carried out in extension programs, this study seeks to understand not only their immediate pedagogical objectives, but also the epistemological foundations that guide these practices and their implications for teacher education.

Morin (2011) argues for the need to establish a new educational paradigm that promotes complex knowledge. To achieve this, we must learn to replace a pedagogy of certainties with a pedagogy of inquiry, in which pre-established knowledge gives way to the search for and analysis of information, enabling the transition from simplicity to complexity (Costa, 2003). Building knowledge that takes into account the complexity of phenomena requires dialogue and integration among different fields of knowledge, implying a paradigm shift in academic education (Tavares & Freitas, 2016) and transformations in higher education institutions. From this perspective, Morin (2022) advocates for a reform of thought linked to a reform of the university, so that it can adapt to the demands of contemporary society. In this context, university extension programs emerge as a transformative process, based on dialogue between the university and society (Ministry of Education, 2018), fostering exchanges of knowledge that enrich students' theoretical and methodological training.

By serving as a two-way channel between the knowledge of teacher-candidates and practicing teachers, university extension programs can help overcome oversimplified paradigms and empiricist conceptions in experimental activities within science education, **depending on the pedagogical and epistemological concepts that guide these initiatives, thereby promoting, in certain contexts, shifts toward new paradigms within** educational institutions. Based on this approach, the objective of this study was to investigate discussions within the Brazilian scientific community in the field of science education regarding experimentation in outreach initiatives, using the "state-of-the-art" methodology.

Methodology

To conduct this study[2], which aimed to investigate discussions within the Brazilian scientific community in the field of science education regarding experimentation in extension initiatives, we adopted the "state-of-the-art" approach as our research methodology. Nóbrega-Thierren and Thierren (2004) define this as a type of literature review that aims to map, systematize, and interpret the academic literature on a specific topic, thereby enabling the identification of trends, recurring themes, gaps, and theoretical and methodological approaches within the field under investigation. Unlike purely descriptive accounts, this approach leaves room for a critical analysis of the knowledge produced, situating the subject of study within its scientific and historical context.

In this study, the state of the art was used for analytical and interpretive purposes, with the aim of understanding how experimentation in extension activities has been addressed in Brazilian academic literature. To this end, a search for studies was conducted on the Oasisbr portal, a Brazilian open-access database of scientific publications, focusing specifically on the field of science education. The search was conducted in March 2024 and covered publications from 2001 to 2023, using the combination of the search terms "extension," "project," and "experimentation" in Portuguese.

After initially identifying 118 publications, we conducted an exploratory review of the titles, abstracts, and keywords, resulting in a final selection of 88 studies. Next, the selected texts were read in their entirety, followed by the gradual application of inclusion criteria: (a) articles published in journals, theses, dissertations, and final course projects; (b) studies whose research focus was on experimentation in extension activities; (c) studies published between 2001 and 2023 in Portuguese. We defined the following exclusion criteria: (a) studies that did not mention the search terms in their titles, abstracts, and/or keywords; (b) publications such as letters, reviews, editorials, presentations, conference proceedings, books, book chapters, and newsletters; (c) articles that were not available online, free of charge, in their full text for analysis; (d) duplicate studies. This procedure was designed to ensure transparency and consistency in the analytical decisions, maintaining alignment between the thematic focus, the criteria used, and the studies analyzed. Following this process of inclusion and exclusion, 14 studies were included in the analytical corpus, as shown in Figure 1.

2 This study is an excerpt from the first author's ongoing doctoral research, conducted as part of a graduate program in science education at a Brazilian public university.

Figure 1

Articles selected by journal using a code

Journal/University	Year	Author(s)	Code
Research, Society and Development	2021	Silva, L. K. A. da et al.	A1
Revista de Ensino de Ciências e Matemática	2020	Santos, B. M. et al.	A2
Revista Prática Docente (RPD)	2018	Amorim, A. M. A. de et al.	A3
Revista Ciências Exatas e Naturais	2007	Mehl, H. et al.	A4
Revista Ciências Exatas e Naturais	2007	Stange, C. E. B. et al.	A5
Revista de Ensino de Bioquímica	2018	Anjos, L. R. B. dos et al.	A6
Universidade Federal do Rio Grande do Sul (UFRGS)	2023	Silva, S. da	T1
Universidade Estadual Paulista (UNESP)	2009	Cunha, T. A. S.	T2
Universidade Federal do Rio Grande do Sul (UFRGS)	2015	Venturi, V.	T3
Universidade Federal de Campina Grande (UFCG)	2017	Silva, F. M. da	T4
Universidade Federal do Rio de Janeiro (UFRJ)	2014	Francisco, T. V.	T5
Universidade Federal Fluminense (UFF)	2022	Marques, M. R.	T6
Universidade de Brasília (UnB)	2020	Farias, V. A. de	D1
Universidade de São Paulo (USP)	2006	Silva, A. de F. A. da	D2

In a descriptive analysis, we found that half of the outreach activities consist of educational workshops and one-off interventions in schools, with most of the hands-on activities organized through demonstrations and predefined scripts (A1, A2, A3, A4, A5, A6, and T4). In a descriptive analysis, we found that half of the outreach activities consist of educational workshops and one-off interventions in schools, with most of the hands-on activities organized through demonstrations and predefined scripts (A1, A2, A3, A4, A5, A6, and T4). T5 features a hybrid model of collaboration between universities and schools, combining systematic monitoring with the development of experiential activities in both school and university settings. The T6 project involves the implementation of a science club that operates on an ongoing basis with elementary and middle school students, featuring regular meetings and a greater emphasis on inquiry-based learning.

Figure 1 presents the selected articles, which were analyzed using Discursive Textual Analysis (DTA), as proposed by Moraes and Galiazzi (2016). As part of qualitative research, DTA aims to understand and reconstruct existing knowledge, moving beyond linear scientific perspectives by adopting complexity and self-organization as the foundations for generating new insights. **In this sense, DTA is understood in this study not merely as an analytical procedure, but as an approach consistent with the complexity paradigm, as it enables researchers, in dialogue with the studies under analysis, to interpret educational phenomena without reducing them to linear or fragmented relationships, while recognizing emergence, recursion, and the interplay among multiple meanings.** In this context, linear thinking gives way to complex and emergent thinking, in line with the ideas of complex systems as understood by Morin.

In this study, DTA was implemented as a recursive process of intensive reading of the analysis corpus to create the 199 units of meaning, guided by the research problem and supported by the theoretical framework adopted and the meanings constructed during the interpretive process. The formation of units of meaning and the construction of categories took place through successive processes of comparison, alignment, and reorganization of textual fragments, with the aim of clarifying conceptions regarding the objectives of the experimental activities and their epistemological assumptions.

Although derived from the corpus, these units of meaning were interpreted in light of the debate between the simplifying paradigm and the complexity paradigm, highlighting the interpretive nature of the analysis. The analysis process began with the unitarization stage, during which the texts were broken down into fragments in search of meaning and significance. These units were included based on excerpts from the texts that outlined the objectives of the experimental activities, how the practices were organized, conceptions of teaching and learning, and references to extension activities. Next, we assigned codes to these units to make them easier to locate in the original text. To do this, we use a letter that indicates the type of work: "A" for journal articles, 'T' for term papers, and "D" for dissertations. The first number refers to the work being analyzed, while the second indicates the location of the passage within the original text.

During the categorization phase, relationships were established among the elements, resulting in 14 initial categories. These categories reflect patterns and recurring themes in the discourses analyzed, particularly with regard to the degree of direction in experimental activities, the investigative elements present in the practices, and the epistemological models that emerge. Thus, based on these categories and through a descriptive and interpretive process, we identified three main categories: "Degrees of focus of experimental activities revealed in extension projects," "Between verification and investigation: reframing the objectives of experimental activities in extension initiatives in the teaching of Natural Sciences," and "Epistemological models evidenced in the use of experimental activities," which are presented in Figure 2.

Figure 2

Final Categories via Initial Categories

Initial Categories	**Final Categories**
Demonstrative experimental activities designed to familiarize students with the laboratory environment and to verify theoretical concepts.	Degrees of focus in experimental activities revealed in extension projects.
Use of structured scripts in theory testing.	
Potential for investigative experimental activities identified by undergraduate students in extension projects.	
Experimental activities facilitate the understanding, assimilation, and retention of content.	Between verification and inquiry: redefining the objectives of experimental activities in outreach initiatives in the teaching of natural sciences.
Elements of the investigation during the conduct of verification activities.	
Experiments and contextualization to facilitate understanding of the phenomena.	
Dialogue in experimentation: exploring the "whys" through experiments.	
Discussion of experiments with unexpected results.	
The importance of understanding students' prior knowledge for the use of experimental activities.	Epistemological models evident in the use of experimental activities.
Experimentation and the building of cognitive bridges for meaningful learning.	
Knowledge construction and subjectivity in experimental activities.	
Mediation: A New Teaching Approach to Designing Experimental Activities	
Criticism of the lecture-based teaching model.	
Teachers' adaptation to lecture-based teaching models.	

Figure 3 shows the distribution of the selected studies by categories identified in the analysis. Because it is directly linked to the field of linguistic studies, DTA is not limited to a purely classificatory approach to data. Thus, the categorization process does not necessarily follow the principle of mutual exclusivity, according to which each individual element can belong to only one category. Similarly, the studies analyzed in this research are not limited to a single meaning, which allows them to be classified into more than one category.

Figure 3

Distribution of academic papers by category

Degrees of focus in experimental activities revealed in extension projects.	Between verification and inquiry: redefining the objectives of experimental activities in outreach initiatives in the teaching of natural sciences.	Epistemological models evident in the use of experimental activities.
A1, A2, A3, T2, T4, T6, D1, D2.	A1, A2, A3, A4, T3, T6, D1, D2.	A1, A6, T2, T3, T4, T6, D2.

Based on this framework, we will discuss the results of this study through the analysis of metatexts, in which the meanings emerging from the final categories are interpreted in light of the theoretical framework adopted, highlighting the contributions of experimentation and outreach projects to science education.

Degrees of Focus in Experimental Activities Revealed in Extension Projects

In this category, we will present the different levels of focus observed in the experimental activities carried out as part of the outreach initiatives in the field of science education, which is the focus of this study. Although experimentation is considered essential to science education, the scientific community has increasingly questioned the practice of limiting its objectives to the mere verification of theories, as noted in A3.2.

> The experiment proposed in the teaching sequence demonstrates the phenomenon of thermal inversion by placing two bottles connected at their caps, with a gap in between, to allow contact between the fluids and their movement when physical conditions permit (A3.2).

These discussions become even more relevant when we consider the potential of hands-on activities to spark curiosity, encourage reflection, and put scientific concepts into context. However, the way these activities are designed—ranging from highly structured lesson plans to more open-ended and inquiry-based approaches—directly influences student learning and engagement.

A1.4, A3.1, and A2.1 also refer to this tendency to validate theory through a demonstrative experiment, as they suggest a closed, teacher-centered demonstrative activity focused on demonstrating established truths. According to Silva et al. (2012), when using this type of activity, teachers believe that simply having students watch the experiment being demonstrated is sufficient for learning to take place. Thus, exposure to a sensory stimulus would be sufficient to ensure effective learning, since, for this teacher, "[...] learning and teaching are a one-way street, in which the object determines the knowledge the learner will acquire during the demonstration" (Silva et al., 2012, p. 137). From this perspective, an inherent aspect of this type of activity is the notion that the teacher should guide what the students will observe, as highlighted in A1.6.

> [...] When teaching science in a school setting, it is necessary to guide what students will observe, since the teaching-learning process should not be built on a conceptual vacuum, nor should it rely solely on perceptions associated with mere observation (A1.6).

This approach to conducting experiments disregards students' knowledge and interests, as its primary goal is to demonstrate the validity of a scientific claim. According to Rosito (2003, p. 203), an activity conducted in this manner "[...] can be valuable provided that the teacher, building on the demonstration, encourages students to seek explanations that will help them understand the phenomenon." The author argues that it is essential for action and reflection to be integrated into experimental activities. Oliveira (2010) shares this view, emphasizing the importance of creating opportunities for students to reflect on the phenomena they observe, formulate hypotheses, analyze variables, and discuss related scientific content. Although demonstrative experimental activities are often structured and guided by the teacher's objectives, thereby limiting discussions about the activity, it is essential to encourage students' active participation in the process of analyzing and interpreting phenomena.

As we saw in excerpts A2.2 and A2.3, demonstration experiments are a powerful tool for sparking curiosity and capturing students' attention regarding the topic at hand. However, students may not be familiar with this teaching tool or with the lab environment. In this regard, hands-on experiments could help address these issues.

> These club members' first encounter with the school's laboratory took the form of an activity that was more of a demonstration than a hands-on exercise, though it was held inside the laboratory; they were able to move about freely, interact with the laboratory materials, and, through the activity and with guidance, develop scientific knowledge. This initial activity was extremely important in consolidating knowledge and demonstrated the importance of using the laboratory (T6.10).

Some scholars (Laburú & Arruda, 1996; Araújo & Abib, 2003; Oliveira, 2010) emphasize that experimental lessons in schools should begin with simpler, more structured approaches, such as demonstration and verification activities. In this way, students could become familiar with this teaching strategy and the laboratory environment, so that they could later conduct more open-ended experiments.

However, despite the various ways of organizing experimental activities, most laboratories follow highly structured protocols, similar to "cooking recipes" (Carvalho, 2010). This was evident in the study, in which half of the studies analyzed used a structured protocol. This type of activity is characterized by providing specific and detailed instructions that students must follow to complete the experiment, such as adopting a theoretical framework; handling specific laboratory materials; and collecting, analyzing, and interpreting data in accordance with the theory to be tested (Rosito, 2003). Portanto, são, em sua maioria, atividades quantitativas e verificacionistas (Araújo & Abib, 2003).

The T4 thesis describes a study conducted as part of an outreach project, in which structured lesson plans were developed for students to follow at home and subsequently present the activities they had completed in the classroom. The analysis revealed that "[...] the students were unable to fully grasp the concepts behind their experiments" (T4.8). In this regard, Rosito (2003) cautions that scientific learning cannot be achieved simply through scripts or "recipe-style" experimental activities that follow an ordered sequence of steps applicable to any situation. According to the author, without sufficient time for reflection and discussion, lab classes become meaningless to students and fall far short of the instructor's expectations. When conducting the DNA extraction experiment in one of the selected studies, it was found that:

> Experimental activities designed and carried out solely to "prove" laws and theories to students fall short of the goals of education and the acquisition of basic knowledge. In this regard, an experimental activity should facilitate discussion and interpretation of the results obtained, with the teacher present to introduce and explain the concepts, laws, and theories related to the experiment (D1.9).

In general, experimental activities with a verificationist approach do not provide opportunities for reflection or in-depth discussion of the subject matter. Instead, they limit themselves to verifying the empirical data presented in textbooks or theoretical lectures (Araújo & Abib, 2003; Villatorre et al., 2008). However, the view that experimental activities serve merely as a means of verification is quite common among teachers, as evidenced by the statement of a participant in one of the extension projects analyzed, who remarked that "[...] it is necessary to explain first, and then demonstrate in practice how and why that result was obtained" (D2.14). As we have observed, in this type of activity, the student's focus is on the outcome, rather than on exploring the phenomena, as in an investigative activity (Borges, 2002).

Investigative experiments represent a strategy that allows students to take a more active role in the process of knowledge construction (Azevedo, 2016). Oliveira (2010) argues that the inquiry-based method has proven effective in developing key aspects of science education. In this type of activity, students must design and identify an interesting problem to solve, "[...] but they should not rely on automatic procedures to arrive at a more or less immediate solution [...]" (Oliveira, 2010, p. 150). Student teachers who used experimental activities with a research focus in high school classrooms found that these activities "[...] spark students' curiosity and interest, encourage classroom participation, put chemical concepts into context, promote better learning, stimulate creativity, and offer students an innovative and unique experience" (T2.7).

Investigative experimental activities do not rely on rigid scripts that leave little room for student input. Unlike demonstration and verification activities, the content is addressed within the context of the activity itself, seeking answers to students' questions and explanations for the phenomena observed. In this process, students are encouraged to reflect on, question, and discuss the scientific concepts underlying the phenomena being investigated.

There is no doubt that hands-on activities play a vital role in science education, as they provide students with opportunities to experience scientific phenomena in a practical and meaningful way. Nevertheless, this study, conducted in the context of outreach activities in science education, revealed tensions and shifts in the objectives of experimental activities, particularly when practices focused on simply verifying theories—such as demonstration experiments and the use of highly structured protocols—have limitations, in that they restrict students' active participation. For hands-on activities to be more effective in the teaching and learning process, it is essential that the lesson plan include time for reflection and discussion of the topics covered in the experiments. Therefore, it is essential that these activities be reimagined through an inquiry-based approach that fosters reflection, autonomy, and the development of meaningful knowledge. In addition, teaching practices that take into account students' prior knowledge and interests tend to foster greater engagement and the development of more lasting knowledge.

From this perspective, striking a balance between the varying degrees of guidance in experimental activities can serve multiple pedagogical objectives, ranging from familiarizing students with the laboratory environment to fostering reflective, autonomous, and meaningful learning, in line with contemporary demands in science education. Therefore, in the next section, we present the key aspects of the experimental activities in the extension projects analyzed, highlighting how these practices can stimulate students' curiosity, promote the contextualization of content, and emphasize the role of error as an essential part of the learning process.

Between Verification and Inquiry: Redefining the Objectives of Experimental Activities in Outreach Initiatives in the Teaching of Natural Sciences

In this category, we discuss how, in the context of extension activities, the objectives of experimentation shift from an emphasis on testing theories to approaches that promote inquiry, contextualization, and the recognition of unexpected results as part of the process of constructing scientific knowledge.

When discussing how experimental activities should be conducted in outreach settings, such as science clubs, one of the studies emphasizes that these activities should foster students' creativity, autonomy, and sense of responsibility, sparking their interest, curiosity, and problem-solving skills, while also reinforcing their knowledge—all of which positively influences their social, personal, and professional development (T6.16). According to Rosito (2003), effective experimental activities should be based on solving problems that reflect students' real-life experiences, thereby generating cognitive conflicts. Thus, according to the author, science education offers a view of science as a complex and socially constructed activity in which there is no universal method for solving all problems. Rather, it is a dynamic and interactive activity characterized by a continuous interplay between thought and action, as described in one of the researchers' reports.

> [...] if we truly want students to learn the material covered, we need to create teaching situations that foster an intellectually stimulating environment in which the child is actively engaged. Therefore, provide hands-on, context-based activities that give children opportunities to express their ideas, test them, and experiment with them safely, as well as to interact with objects and observe how they react. An investigative activity that allows children to ask appropriate questions, conduct the investigation, address the problem situation, and communicate what they see, observe, or think (D2.17).

Azevedo (2016) explains that students learn more about science and develop their conceptual knowledge more effectively when they participate in scientific investigations. An investigative experimental activity enables students to take charge of their own learning and consciously reflect on the topic being studied, thereby allowing them to construct knowledge under the guidance of their teachers (Fagundes, 2007; Oliveira, 2010). In this way, through an investigative activity, students can come to understand that scientific knowledge is constructed, unlike the approaches often presented in science textbooks, where the "scientific method" is portrayed as a fixed process with steps to be followed in a logical sequence. This may lead students to believe in a closed science based solely on observation (Azevedo, 2016).

Another aspect highlighted in the studies reviewed concerns student participation in the planning of research projects. In developing a proposal for inquiry-based science instruction, the participating students expressed "[...] a significant concern with fostering greater student involvement in their lesson plans" (D2.25), consistent with studies conducted by Rosito (2003). According to the author, student participation in the planning of experiments is one of the factors that should be taken into account when designing experimental activities with an investigative focus. From this perspective, an investigative experiment should encourage student participation in all stages of the research process, including research, planning, carrying out the activity, and discussing the findings (Oliveira, 2010).

Morin (2011), on the other hand, argues that for information and data to make sense, they must be placed in their proper context. According to him, "[...] all knowledge must contextualize its object in order to be relevant" (Morin, 2011, p. 47). However, scientific culture fragments and compartmentalizes knowledge, making it increasingly difficult to contextualize it. This statement is supported by a study conducted by Rezende and Ostermann (2005), which found that many teachers cite the difficulty of relating theoretical content to everyday phenomena as one of the main pedagogical problems identified in schools.

From elementary school onward, we are led to compartmentalize knowledge, obscuring the connections between subjects, which reduces the complex to the simple (Morin, 2011). This reduces human complexities to mechanical and deterministic processes, excluding anything that cannot be quantified. However, Morin (2011) argues that relevant knowledge must address complexity, since the challenges of the planetary era require a multidimensional and global approach to education. Hence, "[...] in science education, experimentation can be an effective strategy for creating real-world problems that allow for contextualization and encourage investigative questioning" (A1.5), promoting greater integration among different areas of knowledge and disciplines. Therefore,

> [...] Through contextualized hands-on activities, students can observe phenomena, test hypotheses, and work with their peers to develop possible solutions to the problem at hand, as well as engage in reflective exercises by analyzing the results obtained (D2.12).

Experiments that are set within a specific context make it easier to understand phenomena, as they allow students to relate to real-life situations and recognize the relevance of the material being studied. Furthermore, the importance of dialogue and discussion between students and the teacher is emphasized in this process. Questioning and critical analysis are essential, as they encourage students to explore different perspectives and deepen their understanding of the topics covered, as illustrated in the following excerpt.

> If an instructor assigns the construction of a FC[3] to a group of students, it is important that they ask questions and encourage discussion during this phase. This is intended to encourage students to connect the materials and procedures with scientific concepts. The teacher might ask, for example, why HB pencils are used, or might encourage a discussion about LEDs and their everyday applications (A4.1).

According to Silva et al. (2012, p. 133), the start of an experimental activity should be guided by a question, since questions "[...] reveal what we already know about the subject to be studied and what we wish to learn." In this epistemological context, questions are intended to raise doubts and challenge students' prior conceptions of the phenomena. Therefore, it is essential that the questions and problems presented encourage students to build new knowledge based on what they have already learned, through a Socratic dialogue in which students are invited to participate actively, particularly through reflection (Moraes, 2003). In this way, the teacher can challenge the theories that students bring from their cultural background, creating conditions for them to revise their hypotheses (Silva et al., 2012) and relate them to scientific concepts. In the studies we analyzed, we identified this perception. One of the researchers notes that, by conducting the experiment in a dialogic manner, it was possible to connect the chemistry and biology concepts related to DNA with the students' real-world experiences, thereby facilitating their understanding of scientific phenomena (D1.20). In this regard, Pirez and Araujo (2025) argue that, through the connection between disciplines, complex thinking emerges as a means of understanding issues related to students' lived experiences.

3 FC is an abbreviation for fuel cell, which is a system that converts chemical energy into electrical energy.

However, the results obtained during experiments often do not match the theory that explains the phenomena, and are therefore considered errors to be discarded. This view stems from the myth that science is built solely on correct answers, with no room for error, reinforcing the idea of absolute and indisputable scientific knowledge (Silva et al., 2012). However, this study highlighted how, in the works analyzed, experiments yielding unexpected results have helped shift the focus of experimentation from the verification of theories to an understanding of science as a dynamic process, subject to errors and limitations (T3.5).

Morin (2011) points out that the unexpected takes us by surprise because we have become comfortably settled in our theories and ideas. Although scientific theories are the only ones that allow for the possibility of being disproved, they often resist information that does not fit their assumptions or that they cannot incorporate. However, throughout the 20th century, the sciences have revealed numerous areas of uncertainty, making it essential today to teach strategies for dealing with the unforeseen, the unexpected, and uncertainty. In this regard, Costa (2003) argues that a new paradigm is emerging in which science is no longer tied to certainty. The author argues for the need for an educational approach focused on contemporary science—one that is more pluralistic, dynamic, and open—in which the only certainty lies in the constant deconstruction of the process of constructing scientific knowledge. Thus, we should view errors or unexpected results in an experiment as a starting point, the endpoint of which is a provisional truth, as discussed in one of the outreach projects included in this study.

> Another issue we aim to address in this project is what happens when we conduct an experiment and the results differ from what we expected. In this context, we aim to discuss with the graduate students the importance of investigating, together with the student, the effect of a variable or factor that was not taken into account or arose unexpectedly during the experiment. In this way, the student teacher will be able to conduct experiments with the understanding that, in science education, discussing results that differ from expectations can be a valuable learning tool (D1.16).

This approach to conducting experimental activities is consistent with the concept of open rationality proposed by Morin (2011), which recognizes error as a fundamental part of the process of knowledge construction. From this perspective, education should focus on identifying and understanding these errors. Thus, open rationality is not bound by dogmas or unquestionable certainties; rather, it is the result of a reasoned debate of ideas, operating in a constant back-and-forth between logic and empirical experience, which allows for adaptation to new information and unforeseen circumstances that arise. In this regard, Costa (2003) argues that the new world is characterized by dynamism and an open rationality, directly linked to the idea that scientific knowledge must be flexible, critical, and self-correcting (Morin, 2011). From this perspective, when unexpected results are valued in experiments, experimental activities break with traditional conceptions of teaching and learning, which often prioritize the rote memorization of content. Instead, they promote an active approach, in which mistakes and uncertainty are valuable components of the learning process.

However, it is not uncommon for teachers to instruct their students to disregard experimental results that do not align with theory, based on the idea that the primary goal of laboratory activities is to reinforce knowledge so that it can be retained for a longer period of time (T6.13; A2.4, A1.3). Costa (2003) criticizes this approach, pointing out that the school environment is dominated by models of "conceptual acquisition," in which students are viewed as a blank slate, with no prior knowledge upon entering the classroom—a view influenced by an empiricist epistemological conception. This approach, reinforced by school curricula, results in an outdated view of science, one that emphasizes the transmission of knowledge and experimentation geared toward "rediscovery," induction, and the demonstration of laws and principles, while disregarding the evolutionary, speculative, and human nature of knowledge.

Costa (2003) argues for the need to break away from the empiricist epistemological conception. Therefore, it is of the utmost importance that teachers, when proposing an experimental activity, be aware of the possibilities so that these activities can go beyond simply reinforcing content. A3.6, for example, points out that the use of charades and hands-on activities are tools that facilitate the understanding of physical phenomena. According to Costa (2003), recent scientific developments, particularly in the field of physics, have redefined the concept of "understanding," which is now understood as the continuous reconstruction of knowledge, which is always provisional. Carretero (1997) adds that students' acquisition of knowledge should be based on establishing meaningful connections between new and prior information, which leads to lasting understanding. Therefore, schools should not only focus on helping students understand the material, but also invest in dynamic and varied activities that reinforce that knowledge, as we observed in A1.

In the experiment described in A1, the solubility of CO_2[4] in soft drinks was investigated, taking into account the effect of pressure. After the experimental activity was completed, supplementary texts were used to provide context for the concepts discussed. Although the researchers emphasized the importance of the experiment for content assimilation (A1.13), we believe that true assimilation was achieved only through contextualization. In this regard, Carretero (1997) states that, although hands-on activities are essential for science education, they are not sufficient. True knowledge acquisition requires not only that students connect with the concrete reality addressed by science, but also the development of reasoning skills and problem-solving abilities. Furthermore, it is essential that students build upon their own intellectual resources and prior knowledge, developing a deeper understanding based on their past experiences and personal reasoning.

Thus, investigative experimental activities can enable students not only to understand scientific phenomena but also to develop critical and reflective skills. By fostering curiosity, dialogue, and active student participation, and by promoting the

4 Chemical formula for carbon dioxide, a gas composed of one carbon atom (C) bonded to two oxygen atoms (O). The solubility of CO_2 is what gives carbonated beverages their effervescent quality, a process that occurs in liquids under high pressure and at low temperatures.

contextualization of content, these practices break away from traditional approaches that often limit teaching to a simplistic and fragmented view of science. Furthermore, by viewing “errors”—or unexpected results obtained in an experiment—as part of the learning process, these activities foster a realistic view of science, moving away from the notion of absolute and unquestionable truths. This approach not only deepens students’ understanding of scientific phenomena but also prepares them to deal with complexity, uncertainty, and contemporary challenges, reaffirming the relevance of a pedagogy focused on critical reflection and the integration of knowledge.

From this perspective, the study revealed that, within the scope of the extension activities analyzed, although these activities exhibit elements of constructivism in their experimental components, empiricism and the concept of experimentation focused on “rediscovery” remain deeply rooted in the teachers’ pedagogical and epistemological views. While the empiricist model tends to limit experimentation to the mere confirmation of previously established theories, constructivism values error, the unexpected, and the ongoing process of reconstructing knowledge as central elements of learning.

Therefore, when proposing an experimental activity, it is important for teachers to consider its relevance to student learning, assessing whether the goal is merely to memorize content or to understand natural phenomena in all their complexity. In this context, we recognize that, within the scope of this analysis, a more effective science education—one that is aligned with the demands of contemporary society—requires moving beyond traditional empiricist practices and adopting constructivist approaches. In these approaches, experimental activities, when carried out as part of extension programs, can promote contextualization, dialogue, and discussion of the unexpected results obtained in the experiments, thereby fostering understanding and the consolidation of knowledge. In the next section, we will examine how different epistemological models are reflected in the experimental activities carried out as part of extension programs.

Epistemological Models Evident in the Use of Experimental Activities

In this discussion, we examine how experimental activities carried out in science education outreach programs are interpreted, within the scope of this study, from the perspective of different epistemological paradigms—specifically the simplifying paradigm and the complex paradigm—as well as their implications for the teaching and learning process. These paradigms reflect different conceptions of the nature of scientific knowledge and the role of experimental activities, which can be designed either to provide direct, simplified explanations of natural phenomena or to facilitate the construction of knowledge while acknowledging its complexity.

Thus, in the study, we found that some of the extension activities were aligned with concepts associated with the simplifying paradigm, which focused experimental activities on testing theories; conversely, some of the texts analyzed articulated concepts compatible with the complex paradigm, emphasizing students' active participation in the construction of their knowledge. The latter took into account the students' interactions with the experiments and their prior knowledge. Some of the studies analyzed (A1, T2, T3, and T6) emphasize that, despite the challenges, it is essential to build on students' prior knowledge in order for learning to be truly meaningful, as noted in A1.

> The faculty members noted that the outreach initiative was important, as they observed the students' dedication and active participation throughout its implementation. The observed phenomenon may be linked to the fact that meaningful learning was taken into account, in which prior knowledge is a necessary but not sufficient condition (A1.8).

The Theory of Meaningful Learning, cited in this excerpt and developed by David Ausubel, is a constructivist approach that identifies the presence of adequate prior knowledge, students' readiness to learn, and the use of potentially meaningful materials as fundamental conditions for its occurrence (Moreira, 2013). In his theory, Ausubel argued that learning occurs when new information is meaningfully linked to the student's prior knowledge through a cognitive component he calls a "subsumptor." Thus, the teacher's role would be to organize and present the content in a logical and clear manner, helping students connect it to what they already know, thereby creating "cognitive bridges" (Valadares, 2011), as highlighted in A1.7.

Thus, adopting a constructivist approach means recognizing that knowledge is not acquired from scratch, but must be constructed or reconstructed based on existing concepts. From this perspective, experiments can be designed as problems or hypothesis tests (Rosito, 2003), as illustrated below:

> [...] the students were asked if they remembered what yeast was, always drawing on their prior knowledge and everyday experiences to help them build the necessary understanding to answer the questions and explain what would happen in this experiment. The explanation addressed topics such as respiration, global warming, and the greenhouse effect to explain why gases are released and which gas is involved (T6.3).

Hence, a teacher who adopts a constructivist epistemological perspective views the student as an active constructor of meaning and must, therefore, adopt specific attitudes toward students and the learning context, such as the role of a researcher and questioner (Moraes, 2003). For this to happen, it is essential that teachers organize experimental activities in such a way that students can handle and explore the objects of study, creating an environment where they feel comfortable expressing their ideas and asking questions, thereby exercising their intellectual freedom (Silva et al., 2012). In this regard, the teacher acts as a facilitator in the teaching and learning process, prioritizing students' cognitive and independent development and encouraging them to test their ideas through questioning (T6.6; D2.21).

However, this study reveals that, although teachers recognize the pedagogical importance of experimental activities, they often adopt a simplistic view, using experiments solely to verify theories and stimulate students' curiosity (T2.13), a reflection of their epistemological conceptions (Carvalho, 2016; Borges, 2003). We observe, as do Silva et al. (2012), that although there are constructivist influences in their discourse, empiricist conceptions still predominate. Carvalho (2016) suggests that, in order to transform this approach—which focuses on the transmission of knowledge and an empiricist-positivist view of science—teachers must reflect on the dichotomy between theory and practice, considering what they intend to teach and how they do so, as noted by T2.16. The study indicates that resistance to change is exacerbated by a predisposition toward stability and predictability in teaching practice, characteristics associated with epistemological conceptions that tend to oversimplify the complexity of natural phenomena.

Moreira (2013) emphasizes that, although it is common in schools to hear that teaching should be student-centered and focused on "learning to learn," in practice it remains teacher-centered, with knowledge being merely memorized and reproduced on tests. This point is supported by the study by D2, which examines the conceptions of prospective elementary school teachers regarding science teaching and learning. D2.26 indicates that, in addition to inadequate teacher training, the transition to a more student-centered model creates uncertainty and doubts, making it difficult to move beyond rote learning.

In this context, Carvalho (2016) points out that one of the main obstacles to educational reform is the influence of exclusively traditional classes on teacher training. Harres (2022) also points out that teaching methodologies in higher education are still predominantly focused on the mere transmission of facts, highlighting the need for a change in teaching practices, as noted by A6:

> The results of this study corroborate and reinforce what has already been described in the scientific literature, which suggests that it is important to rethink current teaching methods. High schools and institutions of higher education should seek out interactive learning methods designed to encourage students to participate more actively in class and, consequently, achieve satisfactory results in the process of knowledge construction.[...] Practical and dynamic methods are good options for this new approach (A6.5).

Harres (2022) emphasizes that, today, it is clear that learning is a far more complex process than the simple transmission of knowledge—a process that occurs independently of the learner, remains faithful to the original content, and remains stable over time. In line with these insights, Morin (2022) argues for the need for a reform of thought. To this end, according to the author, it would be necessary to establish an "epistemological tithe" at all universities, "[...] which would allocate 10% of the duration of undergraduate programs to a common curriculum, oriented toward the underlying principles of different fields of knowledge [...]" (Morin, 2022, pp. 84–85), with one of its objectives being to address the complexities inherent in different types of knowledge.

This approach is consistent with Law No. 13,005/2014, which establishes the National Education Plan (PNE 2014–2024) and stipulates that extension activities must account for at least 10% (ten percent) of the total course load for undergraduate programs (Brazil, 2018). Extension activities are defined as initiatives that directly involve communities outside the university and include teacher training among their objectives.

In this context, university extension programs can play a significant role in the well-rounded education of students by fostering dialogue, the exchange of knowledge, and engagement with complex issues in contemporary society. In addition to enriching the student experience in theoretical and methodological terms, these activities also contribute to changes in higher education institutions (Brazil, 2018). Thus, extension is an educational process focused on learning, promoting both student development and the reconstruction of the social reality in which they are embedded (Tavares & Freitas, 2016).

Thus, the studies analyzed highlight the importance of projects that adopt new teaching methodologies as a way to break with traditional approaches (T4.15). Overcoming entrenched practices and notions about how learning takes place is no simple task, especially when these practices are reinforced in teacher training programs. However, extension projects have shown the potential to bridge the gap between teaching practice and university research. Harres (2022) notes that several proposals have emerged to move beyond the traditional lecture-based teaching model. The author argues that pedagogical innovation should promote the transition from a teaching approach based on the transmission of knowledge to a research-focused model.

In light of this, Costa (2003) points out that advances in modern science are driving a paradigm shift in contemporary science, since discoveries regarding the laws of nature have shown that knowledge is always provisional and must be constantly constructed. Morin (2011) reinforces this perspective, arguing that a paradigm shift in thinking is essential to effectively articulate and organize knowledge, thereby enabling an understanding of the problems of the contemporary world.

Therefore, the studies analyzed in this category demonstrated that the experimental activities carried out in Science Education extension programs reflect different ways of addressing the complexity of natural phenomena, ranging from practices aligned with the simplifying paradigm to approaches that engage with Morin's (2011) complex paradigm. Empiricism, which holds that all knowledge must be acquired through sensory experience, tends to focus on observations and concrete data, often disregarding students' prior knowledge. In the simplistic paradigm, this approach manifests itself in the pursuit of measurable results and the use of controlled experiments, typically through scripts or closed demonstrations. With its emphasis on the collection and objective analysis of data, empiricism aligns with the principles of the simplifying paradigm, which seeks to reduce complex phenomena to simpler and more straightforward explanations. However, this approach to conducting experiments may limit our understanding of inherently complex phenomena, as empiricism tends to overlook the broader context that influences the results.

On the other hand, some studies highlight the importance of students constructing their own knowledge, emphasizing that learning occurs through the interaction between the learner, the subject matter, and the learner's prior knowledge—characteristics of constructivism. This approach aligns with the complex paradigm, which advocates for an education that acknowledges the complexity of the world, emphasizing the importance of contextualization and preparing students to deal with uncertainty, while viewing error as fundamental to the process of knowledge construction. Thus, the focus would be on more open and flexible experimental activities, allowing students to explore, ask questions, and construct meaning through open-ended demonstrations or investigative activities.

In light of this, we believe that adopting approaches that bridge the gap between the simplistic and complex paradigms holds promise, as they offer significant potential to transform Science Education, particularly with regard to the role of experimental activities. To this end, it is essential that teachers and student teachers reflect on their epistemological conceptions and pedagogical practices, going beyond the mere testing of theories through experiments.

In this context, we understand that, among the studies analyzed in this State of the Art, extension projects play an important role by integrating research and teaching, bridging the gap between the university and the classroom, and enabling the implementation of experimental, inquiry-based activities that emphasize contextualization and students' active participation in the construction of knowledge, recognizing both the importance of prior knowledge and the complexity of scientific phenomena. Investing in these projects is essential to overcoming traditionalism and establishing teaching practices that are better aligned with contemporary needs, thereby contributing to a transformative and meaningful education.

Final Remarks

This study examined discussions within the Brazilian scientific community in the field of science education regarding experimentation in outreach initiatives. The results showed that empiricist epistemological views still predominate, leading to the continuation of traditional practices in many teaching laboratories. In these practices, the focus is on testing theories through structured lesson plans and demonstrative experiments. This scenario reflects the reality of many teacher-training programs, where lecture-based classes and methodologies focused on the transmission of facts still prevail, reinforcing the persistence of a simplistic paradigm in experimental teaching.

At the same time, an analysis of the selected studies revealed shifts in these concepts, indicating a convergence with constructivist perspectives, which this study interprets in dialogue with the assumptions of the complexity paradigm. In such cases, experimental activities begin to take into account students' prior knowledge, the contextualization of phenomena, and the analysis of the situations under investigation, thereby creating more opportunities for reflection and active student participation. Our analysis reveals that, in some of the studies, there is a gradual shift from a pedagogy of certainty—centered on reproducing expected results—to a pedagogy of the problem, in which errors and unexpected results are integral to the process of knowledge construction and challenge the view of science as cumulative, definitive, and linear knowledge.

However, outreach projects are not viewed as a solution to the long-standing challenges in science education, but rather as a possible avenue for rethinking experimental activities in teacher training. By integrating experimentation into specific educational contexts and fostering dialogue between universities and schools, these initiatives can broaden the methodological repertoire of future teachers by creating opportunities for critical reflection on the objectives of experimental activities in the context of science education.

From this perspective, the contribution of this study does not lie in proposing generalizable models or solutions, but rather in clarifying the epistemological shifts identified in the analyzed literature and in understanding the university setting as a space where different conceptions of experimentation coexist, clash, and can be reinterpreted. By bringing undergraduate students closer to the realities of the school environment and helping to contextualize the phenomena under investigation, extension programs can create the conditions for reevaluating practices rooted in the simplifying paradigm and for strengthening approaches that engage with the complexity paradigm.

Authors' Contribution

Conceptualization: Pirez, D. R. M., Araujo, R. R.; **Data curation:** Pirez, D. R. M.; **Formal analysis:** Pirez, D. R. M., Araujo, R. R.; **Investigation:** Pirez, D. R. M., Araujo, R. R., Heckler, V.; **Methodology:** Pirez, D. R. M.; **Writing – original draft:** Pirez, D. R. M.; **Writing – review & editing:** Araujo, R. R., Heckler, V.

Data Availability Statement

The data will be provided upon request.

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Daiane Rattmann Magalhães Pirez

Universidade Federal do Rio Grande
Rio Grande, Rio Grande do Sul, Brasil
daianepirez2016@gmail.com

Rafaele Rodrigues de Araujo

Universidade Federal do Rio Grande
Rio Grande, Rio Grande do Sul, Brasil
araujo.r.rafa@gmail.com

Valmir Heckler

Universidade Federal do Rio Grande
Rio Grande, Rio Grande do Sul, Brasil
valmirheckler@gmail.com

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