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Towards Greater Understandings of Scientific Practices in Science Education: An Analysis of the Publications

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ABSTRACT

Background: Educational guiding documents in Science Education (NRC, 2012; NGSS, 2013) have given great importance to Scientific Practices. Thus, a greater understanding of what the scientific community understands as Scientific Practices is relevant. **Objectives**: I) To analyse the understandings of the term Scientific Practices in Science Education publications of the last decade (2010-2019); II) to synthesize convergent and divergent points regarding the understandings of Scientific Practices in the literature; and III) to critically discuss trends among the understandings of Scientific Practices in the field of Science Education. **Design**: a qualitative investigation based on Okoli (2015) and Bardin (2011). **Setting**: 44 articles published in international Science Education journals in the last decade (2010-2019). **Data collection and analysis**: An inventory was filled out for each article in order to understand the use and understandings of the term Scientific Practices in the field. **Results**: Three categories emerged regarding the understandings: Articles that presented understandings of Scientific Practices aligned with the National Research Council (NRC) (D1); Articles that presented other understandings of Scientific Practices (D2), based on sociological, philosophical and historical references; and Articles that did not present their understandings of Scientific Practices (D3), although the term was used throughout the text. **Conclusions**: Understandings of Scientific Practices aligned with the NRC's discussions represent the dominant conceptualization among the research (59.1%), however clear and explicit definitions for Scientific Practices, as well as deepening the theoretical discussions of Scientific Practices is still required in Science Education publications due to the different understandings present in the field.

Keywords: Scientific practices; NRC; Understandings

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Compreensões das Práticas Científicas no Ensino de Ciências: uma Análise das Publicações

RESUMO

Contexto: Documentos orientadores educacionais em Ensino de Ciências (NRC, 2012; NGSS, 2013) têm dado grande importância às Práticas Científicas. Assim, é relevante um maior entendimento do que a comunidade científica entende por Práticas Científicas. **Objetivos**: I) Analisar as compreensões do termo Práticas Científicas em publicações de Ensino de Ciências da última década (2010-2019); II) Sintetizar pontos convergentes e divergentes quanto à compreensão das Práticas Científicas na literatura; e III) Discutir criticamente tendências entre as compreensões das Práticas Científicas na área de Ensino de Ciências. **Design**: uma investigação qualitativa baseada em Okoli (2015) e Bardin (2011). **Ambiente e participantes**: 44 artigos publicados em periódicos internacionais de Ensino de Ciências na última década (2010-2019). **Coleta e análise de dados**: Foi realizado um inventário para cada artigo, a fim de compreender o uso e a compreensão do termo Práticas Científicas na área. **Resultados**: Emergiram três categorias quanto às compreensões: Artigos que apresentavam compreensões sobre as Práticas Científicas alinhadas ao *National Research Council (NRC)* (D1); Artigos que apresentaram outras compreensões das Práticas Científicas (D2), com base em referenciais sociológicos, filosóficos e históricos; e Artigos que não apresentavam sua compreensão das Práticas Científicas (D3), embora o termo tenha sido utilizado ao longo do texto. **Conclusões**: As compreensões das Práticas Científicas alinhadas às discussões do NRC representam a conceituação dominante entre as pesquisas (59,1%), porém definições claras e explícitas para as Práticas Científicas, bem como o aprofundamento das discussões teóricas das Práticas Científicas ainda são necessárias nas publicações de Ensino de Ciências devido aos diferentes entendimentos presentes na área.

Palavras-chave: Práticas científicas; NRC; Compreensões

INTRODUCTION

The National Research Council published in 2012 *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. The NRC (2012) considers the document to be a first step in a process of developing new standards in Science Education, as well as an important step in the strengthening of national documents on Science Education in the United States, which were last developed in the 1990s. The framework highlights the importance of integrating science ideas with involvement in Scientific Practices and was designed to establish the proficiency and assessment of students in science throughout school years. The framework is designed around three main dimensions: 1) Scientific and Engineering Practices; 2) Crosscutting concepts that unify the study of Science and Engineering through its common application in all fields; and 3) Core Ideas in four domains.

The relevance of this research can be attributed to the importance given to Scientific Practices in recent international educational documents (NRC, 2012; NGSS, 2013) and the adoption of standards based on Scientific Practices (National Science Teaching Association). The *Next Generation Science Standards* (NGSS), for example, is an interstate movement in the United States that aims to create new standards which are rich in content and practice, organized in a coherent way to provide students science education with international references (NGSS, 2013). The standards have three dimensions: the Core Ideas, which consist of specific content and thematic domains; Scientific Practices, which guide students to not only learn the content, but also to understand the methods of scientists and engineers; and Crosscutting Concepts, which are the main underlying ideas common to various topics in science.

According to the NTSA - National Science Teaching Association, 44 states (representing 71% of US students) have education standards influenced by the NRC (2012) and 20 states have already adopted the standards, representing more than 35% of students in the United States (NTSA, 2019). Thus, the concept of Scientific Practices assumes a central role in Science Teaching in the United States, and has been the focus of several studies, including research in other countries (Broietti et al., 2019; Prins et al., 2018; Evagorou et al., 2015).

An independent study, with a focus on investigating the main understandings of Scientific Practices expressed in publications of the last decade can serve to identify if there is a defined and unified understanding of the term in the field, as well as help to clarify the vision of the term internationally. Such study can identify possible convergent and divergent points present in the international literature regarding the conceptualization of Scientific Practices in educational research.

Thus, this research contributes to deepening the understanding of the term Scientific Practices and how it has been understood and discussed in the international literature.

The research questions are:

I) What are the understandings of the term Scientific Practices in Science Education publications of the last decade (2010-2019)?

II) What are the convergent and divergent points regarding the understandings of Scientific Practices in the literature?

III) What are the trends among the understandings of Scientific Practices in the field of Science Education?

The objectives of this research are:

I) To analyse the understandings of the term Scientific Practices in Science Education publications of the last decade (2010-2019);

II) To synthesize convergent and divergent points regarding the understandings of Scientific Practices in the literature;

III) To critically discuss trends among the understandings of Scientific Practices in the field of Science Education.

THEORETICAL BACKGROUND

Scientific Practices, also called Dimension 1, by the NRC, is relevant since:

> Dimension 1 describes (a) the major practices that scientists employ as they investigate and build models and theories about the world and (b) a key set of engineering practices that engineers use as they design and build systems. We use the term "practices" instead of a term such as "skills" to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice (NRC, 2012, p. 30).

The NRC (2012) discusses the integrated use of Scientific Practices to better specify what is meant by research in science and the diversity of cognitive, social and physical practices that it requires. In addition, involvement with Scientific Practices promotes a better understanding of the construction of scientific knowledge, as well as an appreciation for the diversity of approaches used in scientific investigations (NRC, 2012).

In 1989, the American Association for the Advancement of Science (AAAS), through Project 2061, published *Science for All Americans*, defining scientific literacy for all high school students. The first standards in Science Education were published in 1996 by the NRC, titled: *National Science Education Standards* (NRC, 1996). This document established national standards for Science Education and defined guidelines specifically for teaching; the professional development of teachers; assessment; content; Science Education programs and educational systems. One of the main objectives of the document was to promote scientific literacy for students in the United States.

The NRC (1996) discusses the importance of scientific literacy:

> Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed." (NRC, 1996, p. 22).

The 1996 *National Science Education Standards* (NRC, 1996) represent the first set of standards for Science Education and feature only four mentions of the term Scientific Practices. Despite this, the NRC (1996) places a great emphasis on scientific literacy and the establishment of standards centred on teaching and the professional development of teachers (evident in the organization of the document's chapters).

With regards to the early conceptualizations of the term Scientific Practices, it is noticeable that in the *National Science Education Standards* (NRC, 1996) Scientific Practices were always related to the teacher-student relationship. An example of Scientific Practices, according to the NRC (1996) was the judgment used by the teacher during assessments. The NRC (2012) and NGSS (2013) are different from previous documents, in that they present a greater emphasis on science learning over the years, centred on the student and oriented through Scientific Practices, Crosscutting Concepts and Core Ideas, with a more robust definition and discussion of Scientific Practices and how students can get involved in them.

The NRC (2012) presents eight Scientific Practices (SP) (Table 1) considered essential for science learning in basic education, as well as discusses them individually in detail.

Table 1

The NRC's eight Scientific Practices (adapted from NRC, 2012)

Practice	Description
SP1. Asking Questions	Science starts with a question about a phenomenon, for example, "Why is the sky blue?" or "What causes cancer?", and seeks to develop theories that can provide answers to such questions. A basic practice of the scientist is to ask questions that can be answered empirically, to establish what is already known and to determine which questions can still be answered satisfactorily.
SP2. Developing and Using Models	Science often involves building and using a wide variety of models and simulations to help develop explanations of natural phenomena. Models make it possible to go beyond what is observable and imagine a world that has not yet been seen.
SP3. Planning and Carrying Out Investigations	Scientific research can be conducted in the field or in the laboratory. An important practice of scientists is to plan and carry out a systematic investigation, which requires the identification of what should be collected, how it should be collected, what should be treated as a dependent variable, etc. The observation and data collected from such work is used to test existing theories and explanations or to review and develop new theories and explanations.
SP4. Analysing and Interpreting Data	Scientific investigations produce data that must be analysed for meaning. Since the data generally does not speak for itself, scientists use a range of tools, such as - tabulation, graphical interpretation, visualization, and statistical analysis - to identify the significant characteristics

	and patterns in the data. Sources of error are identified and the degree of certainty is calculated. Technology makes collecting a lot of data much easier, providing many secondary sources for analysis.
SP5. Using Mathematics and Computational Thinking	In science, mathematics and computing are fundamental tools for representing variables and their relationships. These are used for a series of tasks, such as the construction of simulations, statistical analysis of data and recognition of quantitative relationships, for example. Mathematical and computational approaches allow predictions of the behaviour of physical systems, along with the confirmation of such predictions. In addition, statistical techniques are invaluable in assessing the significance of patterns or correlations.
SP6. Constructing Explanations	The goal of science is to build theories that can provide explanatory accounts of features of the world. A theory is accepted when it proves to be superior to other explanations about the phenomena. Scientific explanations are explicit applications of the theory to a specific situation or phenomenon. The students' goal is to build coherent and logical explanations of phenomena that incorporate their current understanding of science, or a representative model consistent with the available evidence.
SP7. Engaging in Argument from Evidence	In science, reasoning and arguments are essential to identify strengths and weaknesses in a line of reasoning and to find the best explanation for a natural phenomenon. Scientists must know how to defend their explanations, formulate evidence based on a solid database,

	examine their own understanding in view of the evidence and collaborate with colleagues in the search for the best explanation for the phenomenon investigated.
SP8. Obtaining, Evaluating, and Communicating Information	Science cannot advance if scientists are unable to communicate their findings clearly and persuasively, as well as learn about other people's results. One of the main practices of science, therefore, is the communication of ideas and the results of questioning. This includes oral information, in writing, in tables, diagrams, graphs and equations. Science requires the ability to derive meaning from scientific texts (such as newspapers, the internet and lectures) in order to evaluate scientific knowledge, its validity and integrate information.

In this article, the central focus is on the NRC's first dimension (Scientific Practices). We seek to analyse the understandings of Scientific Practices expressed in publications of the last decade, aiming to clarify the comprehension of this term internationally, as well as to identify possible convergent and divergent points present in international literature.

METHODOLOGY

For Fink (2005), a literature review is a systematic, explicit, comprehensive and reproducible method for identifying, evaluating and synthesizing the existing body of completed works of researchers and scholars. Okoli (2015) presents a guide for a systematic literature review, suggesting eight steps to ensure a rigorous review (Table 2).

Table 2

An eight-step guide to conducting a systematic literature review (adapted from Okoli, 2015)

Step	Description
1) Identify the objective	The first step of any review requires that reviewers clearly identify the purpose of the review and the intended goals. This is necessary for the review to be transparent to readers.
2) Develop the protocol and instruct the team	For any review that employs more than one reviewer, the reviewers must be clear and agree with the procedures they will follow. This requires a written and detailed protocol, as well as an instruction so that all reviewers have consistency in how they will perform the review.
3) Apply a practical screen	This step requires reviewers to be transparent about which studies they have considered for review and which they have eliminated (a much-needed part of any literature review). For excluded studies, reviewers must present their practical reasons for not considering them. The reviewers should also justify how the review remains comprehensive, even with the exclusions, considering the practical exclusion criteria.
4) Search literature	Reviewers need to be transparent and clear when describing the details of searching for literature and need to explain and justify how they ensured the scope of the research.
5) Extract data	After the reviewers have identified all of the studies that should be included in the review, it is necessary to extract systematically the applicable information from each study.

6) Assess quality	This step requires reviewers to explain the criteria that were used to exclude documents of insufficient quality. Researchers must classify all works included, according to the research methodologies or other criteria of their choice.
7) Synthesize studies	This step is also known as analysis, it involves combining the facts extracted from the studies using appropriate techniques, whether quantitative, qualitative or both.
8) Write Review	In addition to the standard principles to be followed when writing research papers, the process of a systematic literature review needs to be reported in sufficient detail so that other researchers can independently reproduce the results of the review.

In this research, step 1 consisted of elaborating the research objectives and problems, as well as the justifications for carrying out this review, presented previously in the Introduction. Step 2 consisted of preparing the protocol for the review, that is, the schedule of research activities. Methodological frameworks (Okoli, 2015) and analytical frameworks (Bardin, 2011) were also selected in step 2.

Step 3 consisted of applying the filters and defining the exclusion criteria. For this review, searches were carried out in four databases: ERIC, Scielo, Scopus and Web of Science. For all databases, the following expressions “scientific practice” and “science education” were inserted. The selected filters were: articles and review articles; peer-reviewed journal articles; open access articles; and articles published in the last ten years (2010-2019). Step 4 consisted of searching the literature. The first search generated 58 results, of which 27 were from ERIC; 1 result was from Scielo; 19 results were from Scopus; and 11 results were from Web of Science.

In step 5, Inventories were used to systematically extract the relevant data for the analysis of the articles. An inventory was filled out for each article in order to understand the use of the term Scientific Practices in the publications, as well as to identify the understandings of Scientific Practices in the field, as followed in other similar studies (Sousa & Vieira, 2019; Costa et al., 2020a; Costa et al., 2020b). For that, the word "practice" was searched in each article and all paragraphs that contained that term were read and transcribed into the inventory. The word "practice" was used, as this term also showed excerpts of the same plural term: "practices", as well as the term in its complete form: "scientific practices" and other variants of the term such as "practices of science". This ensured that all excerpts referring to Scientific Practices were transcribed. Afterwards, all the theoretical references that mentioned Scientific Practices in the articles were transcribed.

In step 6, to assess the quality, all inventories were reread. In this process 14 articles were excluded, leaving 44 articles for further analysis. The exclusions occurred due to some articles: not being of Science Education; being a duplicated result; not being in English, Portuguese or Spanish; and not having any mentions of Scientific Practices. Thus, the corpus of the research was composed of the inventories of 44 articles.

For step 7, Bardin's Content Analysis (2011) was used, defined as:

> A set of techniques for analysing communications in order to obtain, by systematic and objective procedures for describing the content of messages, indicators (quantitative or not) that allow the inference of knowledge related to the production/reception conditions (inferred variables) of these messages (p 48, our translation).

Content Analysis is structured in three stages: *Pre-analysis*; *The exploration of the material*; and *Treatment of results, inference and interpretation*.

In the *pre-analysis*, the organization and systematization of the initial ideas and the processes of making the material operational take place. In this research, the pre-analysis comprised the first contact with the articles, that is, the first reading, as well as the extraction of the necessary information from each article to fill the inventories.

The exploration of the material is the step that consists of coding and enumeration operations according to previously formulated rules. This requires an in-depth study, guided by hypotheses and theoretical references and includes classification and categorization (Bardin, 2011). Coding corresponds to a transformation such as: aggregation and enumeration, to achieve a representation of the content or its expression. In this research, this consisted of: coding the articles from A01-A44 (Table 3); and grouping the articles in categories, according to similar understandings for the term Scientific Practices. The references of all analysed articles can be seen in the "References" section of this article.

Table 3

Codes of the 44 analysed articles

Code	Article
A01	Houseal (2016)
A02	Valenti et al. (2016)
A03	Rosenberg and Lawson (2019)
A04	Rodriguez et al. (2018)
A05	Nicolaou (2015)
A06	Vick and Garvey (2016)
A07	Buxner (2014)
A08	Lunde et al. (2016)
A09	Buck et al. (2014)
A10	Gunning et al. (2016)
A11	Palma et al. (2017)
A12	Tractenberg (2017)
A13	Riedinger and Taylor (2016)
A14	Ayar and Yalvac (2016)
A15	Brownstein and Horvath (2016)
A16	Bardeen et al. (2018)
A17	Koomen et al. (2014)
A18	Bogar (2019)
A19	Engels et al. (2019)
A20	Gotwals et al. (2013)
A21	Carpenter (2015)
A22	Erenler and Cetin (2019)
A23	Iwuanyanwu (2019)
A24	Brandão et al. (2011)
A25	Underwood et al. (2018)
A26	Reed et al. (2017)
A27	Barcellos and Coelho (2019)
A28	Rowland et al. (2018)
A29	Elliott et al. (2016)
A30	Boisselle (2016)

A31	Odden and Russ (2019)
A32	Prins et al. (2018)
A33	Oliva (2019)
A34	López et al. (2018)
A35	Scalise and Clarke□Midura (2018)
A36	Evagorou et al. (2015)
A37	Koomen et al. (2018)
A38	Bierema et al. (2017)
A39	Bargiela et al. (2018)
A40	Kind and Osborne (2017)
A41	Roberts and Johnson (2015)
A42	Dunlop and Veneu (2019)
A43	Lombardi et al. (2018)
A44	Wyner and Doherty (2017)

Finally, the *treatment of results, inference and interpretation* consists of making inferences and interpretations about the predicted objectives (Bardin, 2011). In this study, this step consisted of presenting the understandings of the term Scientific Practices, which were identified through aspects mentioned by the authors of the articles. The identification of convergent and divergent points related to the understandings of Scientific Practices, as well as the discussion of the results were also conducted in this step. Therefore, step 7 involved the three phases of Content Analysis and step 8 consisted of writing this article.

RESULTS AND DISCUSSIONS

The discussions in this section were carried out using the article codes (Table 3). The understandings of Scientific Practices, which were identified through aspects mentioned by the authors of the articles were grouped into three emerging representative categories (Table 4). In order to categorize the understandings, all excerpts containing the term "Scientific Practice", present in the inventory, were read.

Table 4

Representative categories of Scientific Practice understandings

Category	Description	Number of articles
D1	Articles that presented understandings of Scientific Practices aligned with the NRC	26 (59.1%)
D2	Articles that presented other understandings of Scientific Practices	7 (15.9%)
D3	Articles that did not present their understandings of Scientific Practices	11 (25%)

Next, each category will be discussed in more detail. Table 5 presents the articles which presented understandings of Scientific Practices aligned with the NRC (D1). The references in Table 5 refer only to the understandings of Scientific Practices presented in the articles. The complete references can be seen in the "References" section at the end of the present article.

Some articles did not include explicit definitions of Scientific Practice, but contextualized Scientific Practices by citing NRC documents several times. In these cases, it was considered that the authors understood Scientific Practices according to the NRC's discussions, due to the large number of citations mentioning such documents.

Table 5

Articles that presented understandings of Scientific Practices aligned with the NRC

Articles	References
A01	NRC (2012) and NRC (2013)
A03	NGSS (2013) and NRC (2012)
A06	NGSS (2013) and NRC (2012)
A07	NRC (2012) and NGSS (2013)
A09	NRC (2012); Bybee (2011); and Michaels et al. (2008)
A10	NGSS (2013); Minner et al. (2010); Sadler and Zeidler (2004); and NRC (2012)
A11	NRC (2012) and NGSS (2013)
A13	Luehmann (2009)
A15	NGSS (2013)

A16	NGSS (2013)
A17	NRC (2012)
A19	NRC (2012)
A20	NRC (2012)
A23	NRC (2012)
A25	NRC (2012)
A26	NRC (2012) and Brandriet et al. (2015)
A27	Driver et al. (1999)
A31	NRC (2012)
A34	NRC (2012)
A35	NGSS (2013)
A36	NRC (2012) and Duschl et al. (2008)
A37	NGSS (2013); NRC (2012); and Kuhn (1993)
A38	NRC (2012)
A39	NRC (2012) Kelly (2008)
A40	NGSS (2013); NRC (2012); and Passmore and Stewart (2002)
A44	NRC (2012) and NGSS (2013)

It was noted that all articles allocated to category D1 presented ideas from documents prepared by or aligned with the NRC, regarding Scientific Practices. In this sense, A13 and A27 can be highlighted, as they did not directly cite NRC references, but assumed understandings aligned with the NRC. For example, A13 argues that the use of Scientific Practices involves students in fieldwork, as scientists, and that using the real tools of scientists constitutes learning that mirrors the practices of scientists, that is, an idea very much in line with the NRC for Scientific Practices. As per A27, A27 discusses that Scientific Practices help students see themselves as scientists and develop positive scientific identities, since they are the practices of the scientific community.

Among the understandings of Scientific Practices in category D1, the reading and re-reading of the item “Use of the term Scientific Practices” of the inventory of each article was carried out to summarize the main ideas of the authors about Scientific Practices. From this, six main ideas of Scientific Practices were identified (Table 6).

Table 6

The six main ideas of Scientific Practices of category D1

Idea	Description
D1.1	• Scientific Practices are the processes of "doing science". • Scientific practices are a form of procedural knowledge • Scientific practices are procedural skills • Scientific Practices are part of the science process, characterized as cognitive and discursive activities that are directed towards science teaching to develop an epistemic understanding of Science and an appreciation of the nature of science.
D1.2	• Scientific Practices are the activities used by scientists to build knowledge, theories and models about the world • Scientific Practices are the activities of scientists that are done repeatedly with increasing levels of proficiency. • Scientific Practices involve students in fieldwork as scientists, and allow them to use the real tools of scientists, constituting learning that mirrors the practices of scientists. • Scientific Practices mirror the way that scientists build knowledge in science.
D1.3	• Scientific Practices are one of the three dimensions of science learning (Scientific Practices, Core Ideas, and Crosscutting Concepts). • These dimensions are intertwined.
D1.4	• Scientific practices are different from terms such as inquiry and scientific processes, as they emphasize that engaging in scientific investigation requires not

		only skill, but also specific knowledge for each practice.
D1.5	•	Scientific practices in a given subject area (for example, astronomy) can vary dramatically from those in other areas.
	•	Scientific practices are specific to each discipline.
D1.6	•	Scientific Practices are the practices of the scientific community.
	•	Scientific Practices are the specific ways in which community members propose, justify, evaluate and legitimize knowledge claims in a disciplinary structure.

Table 7 presents the articles that express other understandings of Scientific Practices and the respective references cited to support such understandings. These articles were allocated to category D2 and totalled 15.9% (7 articles). The complete references can be seen in the "References" section at the end of the present article.

Table 7

D2: Articles that presented other understandings of Scientific Practices

Articles	References
A14	Pickering (1995); Archer et al. (2010); Ford and Wargo (2006); and NGSS (2013)
A29	O'Malley et al. (2010)
A32	Prins et al. (2008)
A33	Prins et al. (2009)
A41	Roberts and Gott (2006) and NRC (2012)
A42	Harker (2015)
A43	Ford (2015) and NRC (2012)

Some of the articles in category D2 (A14, A41, A43) mentioned the NRC (2012) briefly, only to contextualize the term and exemplify the importance that Scientific Practices have received in guiding documents. In spite of this, these articles went deeper into understandings different from those expressed in the NRC, and were thus allocated to category D2.

A14 briefly comments on the Scientific Practices mentioned by the NGSS (2013), but also presents other references to support different ideas for Scientific Practices (Pickering, 1995; Archer et al., 2010; Ford & Wargo, 2006):

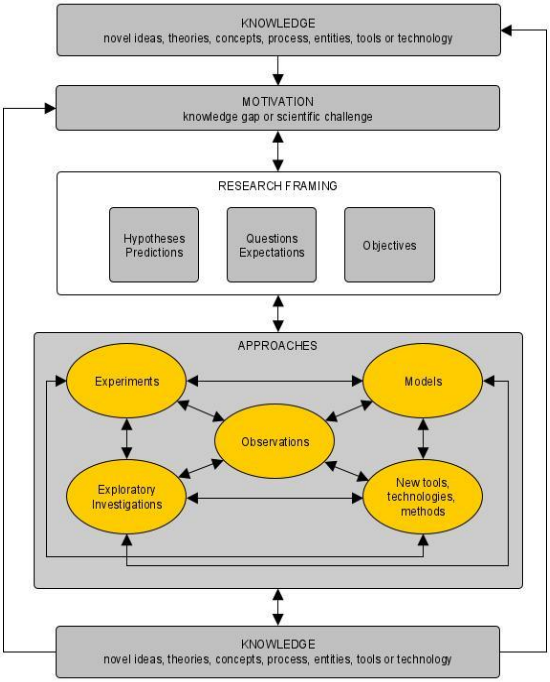
> Pickering (1995) conceptualized scientific practice through intentions, plans, goals, individual interests, and constraints within the framework of 'mangle of practice' (p.23). According to Pickering, the mangle was the dialectic of resistance and accommodation. Resistance, which momentarily emerges, appears to be an obstacle in the path of a scientist's goal. His or her responses to this resistance would be accommodated through working to solve it in a manner that leads to a new machine or new knowledge. Without human intentions or purposes, there would be no development of new machines or new knowledge (A14, p. 32).

A14 uses this framework, among others, to "understand the vision of science as a social practice" (A14, p.32) and provide a conceptual basis for its study, which seeks to discuss: the purposes, responsibilities, common activities, objectives and intentions of subjects from two different academic contexts. A14 seeks to make this analysis from sociological lenses and highlight the distinct characteristics of these contexts, as well as suggest new strategies for learning Science, Technology, Engineering and Mathematics (STEM) at school. A14 also presents the concept of Ford and Wargo (2006), which understand Scientific Practice through routines, roles and responsibilities (3Rs).

On the other hand, A29 represents/understands Scientific Practice as an iterative process, with several approaches and links (Figure 1).

Figure 1

Scientific Practice as an iterative process. (adapted from A29)



For A29:

> An iterative model of scientific practice alleviates many common concerns about data-intensive research. The potential for generating spurious correlations becomes less serious when data-generated patterns are identified and evaluated as part of larger research projects that incorporate broader research questions, hypotheses, or objectives and when appropriate techniques and inferences are used to deal with spurious correlations (Hand, 1998). (A29, p. 5).

From the excerpt above and Figure 1, it is noticed that A29 relates Scientific Practice to iterative scientific research methods. The citation to O'Malley et al. (2010) in A29 corroborates this understanding:

> O'Malley and colleagues (2010) argued that not only data-intensive research but also scientific practice as a whole should be characterized as an iterative interplay between at least four different modes of research: hypothesis-driven, question-driven, exploratory, and tool and method-oriented (A29, p. 5).

A32 seeks to use Authentic Scientific Practices, existing in society, in learning contexts in chemistry. A32 uses the word "workers" to designate the subjects who perform these Practices, instead of using the word "scientists". The values and attitudes of these Practices are also of great importance, because in addition to knowledge (concepts and/or theories), the social insertion of Practice should also be highlighted. We consider that A33 also understands Scientific Practice in this sense, since A33 cites Prins et al. (2009). We emphasize that A33 does not present its explicit understanding of Scientific Practice in the article, however we allocate A33 to category D2 for using the term Authentic Scientific Practice and for quoting Prins et al. (2009) and not any NRC documents.

As for A41: "Viewing scientific practice as a conceptual knowledge base to be understood rather than skills or processes to be acquired represents an ontological shift in its characterization" (A41, p. 3). A41 discusses that recent curriculum documents reflect this change since Scientific Practice is concerned with "doing". According to A41: "Viewing scientific practice as a network of ideas to be understood has significant implications for the role of practical work in science education, its specification in curricula and its assessment (Roberts & Gott, 2006)" (A41, p.18). Thus, A41 was allocated to category D2 for also presenting the understanding of Scientific Practices as a network of ideas to be understood.

A42 also presents a different understanding of Scientific Practices. For A42 Scientific Practice is a dialogical, argumentative and lively activity, involving people in the resolution of controversies, leading to the elaboration or re-elaboration of theories. Therefore, A42 was allocated to category D2 for presenting different understandings of Scientific Practices and not mentioning any NRC documents.

A43 discusses the little importance given to critique and evaluation in Science Education:

> Although A Framework for K–12 Science Education lists evaluation in the title of one of its eight scientific practices (i.e., "obtaining, evaluating, and communicating information," NRC,

> 2012, p. 3; emphasis ours), we agree with Ford's (2015) position that all scientific practices are based on "processes of perpetual evaluation and critique that support progress in explaining nature" (p. 1043) (A43, p.154).

Thus, A43 understands Scientific Practices as perpetual processes of evaluation and criticism that supports progress in explaining nature.

The *articles that did not present their understandings for Scientific Practices* are: A02, A04, A05, A08, A12, A18, A21, A22, A24, A28, A30. These articles were allocated to category D3 and totalled 25% (11 articles) of the corpus. References cannot be discussed, as the authors did not define the term Scientific Practices.

The articles in category D3 did not present explicit definitions for the term Scientific Practice, merely mentioning the expression in the articles. For example, A08 commented that laboratory work can be a way of mirroring aspects of Scientific Practices in the real world - with an emphasis on the nature of science as a process, but did not comment on what it considers to be Scientific Practice. This article also did not mention references from the NRC, and thus could not be allocated to category D1, nor did it mention references from category D2. Therefore, it was allocated to category D3. Similarly, A18 comments that educational reforms have given great prominence to Scientific Practices, but did not include understandings of Scientific Practice, nor did it mention what educational reforms these are. Next, analyses are presented in relation to the understandings expressed in the publications.

A CRITICAL ANALYSIS

Category D1 consisted of the majority of the articles (59.1%) and six main ideas of Scientific Practices could be synthesized from these articles (D1.1, D1.2, D1.3, D1.4, D1.5, and D1.6). These six ideas are relevant to research in Science Education, as they describe the predominant understanding the scientific literature currently has of Scientific Practices. Among these main ideas, a gap in the research can be highlighted, since it is known that Scientific Practices are specific to school disciplines (D1.5), but it is not yet clear which Practices are closer to which disciplines. This is relevant, as it could inform what should be considered in the development of activities and assessments in specific disciplines. A better view of what specific Scientific Practices are closest to specific school disciplines could also provide a better understanding of what activates students are expected to engage in each discipline (student actions).

Category D2 consisted of 15.9% of the articles. These articles often used sociological, philosophical, or historical ideas or lenses to understand Scientific Practices. These articles understood Scientific Practices as: routines, functions and responsibilities (A14); an iterative process, or iterative scientific research methods (A29); performed by workers immersed in society (A32); a network of ideals (A42); and perpetual processes of evaluation and criticism (A43). We consider that category D2's understandings are alternative in Science Education, due to the small number of articles that assumed these understandings (15.9%), as well as the fact that these understandings are different from each other, and not unified or complementary as in category D1.

Category D3 consisted of 25% of the articles. These articles did not present clear and explicit definitions for the term Scientific Practice, only mentioning the term, which demonstrates a portion of the literature which uses such expression without theoretical deepening and clear understandings for the term. The inclusion of understandings of Scientific Practices in the articles is relevant in order to comprehend what the authors understand/assume as Scientific Practices in their studies. This is also important due to the different understandings identified in the corpus.

CONCLUSIONS

Regarding the authors' understandings, three categories emerged (D1, D2, and D3). The articles allocated to category D1, presented understandings of Scientific Practices aligned with the NRC and consisted of the majority of articles (59.1%). Regarding the converging points, six main ideas could be synthesized from the discussions of these articles: Scientific Practices as processes of "doing science"; Scientific Practices as activities that are similar to the activities carried out by scientists in the construction of knowledge; Scientific Practices as one of the three dimensions for science learning; Scientific Practices as a complex and broad term, involving knowledge and skills, Scientific Practices as dependent on the school subject in question and Scientific Practices as practices of a given community. Due to the large number of articles (59.1%) in category D1, the greatest trend in conceptualizing Scientific Practices in the last decade was presenting understandings aligned with the NRC.

Category D2 included articles that presented other understandings of Scientific Practices, using sociological, philosophical, or historical references. We believe that category D2's understandings are alternative in the field of Science Education, due to the small number of articles that assumed these understandings (15.9%). Also, no convergent points were found in this category, besides being different to the understandings of the NRC and having roots in Sociology, Philosophy or History. This is due to the fact that the understandings were very different from each other, and were not unified as in group D1. Thus, these understandings diverge from the majority trend to conceptualize Scientific Practices according to the NRC and constitute an alternative, and smaller trend. We consider that this minor trend understands Scientific Practices as: routines, functions and responsibilities; an iterative process, or iterative scientific research methods; practices carried out by workers immersed in society; a network of ideals; and perpetual processes of evaluation and criticism.

Finally, in category D3 (25%) are the articles that did not explicitly present their understandings of Scientific Practices. These articles did not present definitions for the term, only mentioning it throughout the text. We consider the inclusion of understandings for Scientific Practices in future studies relevant in order to understand what authors comprehend as Scientific Practices and to treat the term as a well-defined concept. Clear and explicit definitions are needed for the term Scientific Practice, in addition to a certain theoretical depth in the discussions, in order to avoid using the term as colloquial and vague in Science Education research, since it may have different conceptual lines (D1 and D2).

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AUTHORS’ CONTRIBUTIONS STATEMENTS

SLRC and FCDB conceived the presented idea. SLRC developed the theoretical background and collected the data. SLRC and FCDB analysed the data and developed the discussion of the results.

DATA AVAILABILITY STATEMENT

The data collected for this research may be made available through contact with the corresponding author, SLRC, with adequate justification.

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