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Scientific practices in science education: a systematic review of research characteristics and trends

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Abstract: Interest in research involving Scientific Practices has increased in recent years due to the importance given to the term in recent Science Education standards. This research presents results of a Systematic Review of articles involving Scientific Practices in Science Education. 44 articles from journals published in the last ten years (2010-2019) were analyzed from four databases: ERIC, Scielo, Scopus, and Web of Science. The objectives were: I) To identify publications involving Scientific Practices in Science Education; II) To synthesize the characteristics of these publications, and III) To critically analyze research trends. A qualitative investigation was carried out guided by Bardin's Content Analysis (2011) and Okoli's guide to a Systematic Review (2015). As a result, it was identified that 26 articles (59.1%) were from North America and 18 (40.9%) from other countries in Europe, South America, Asia, Oceania, and Africa, thus characterizing Scientific Practices as a topic of international repercussion. The increase in research involving Scientific Practices, as seen in 89% of the studies which were published in the second half of the last decade, can be justified due to: 1) The impact of guiding documents which present great emphasis on Scientific Practices; and 2) The preference of some studies to use the concept of three-dimensional learning instead of “inquiry.” Among the most cited references, are the NRC (2012) and NGSS (2013) in 67.6% and 45.9% of the articles, respectively. Research gaps in Scientific Practices are also identified, such as a need for more research with a central focus on the theme, and research that investigates pre-service teacher education. Research in this context is relevant, since Science teaching supported by Scientific Practices is more easily promoted with intentional instruction in the initial training of teachers.
Keywords: Scientific Practices, NRC, Systematic Literature Review, Science Education.

Práticas científicas no ensino de ciências: uma revisão sistemática das características e tendências de pesquisa
Resumo: O interesse por pesquisas envolvendo Práticas Científicas tem aumentado nos últimos anos devido à importância dada ao termo em padrões recentes do Ensino de Ciências. Esta pesquisa apresenta resultados de uma Revisão Sistemática de artigos envolvendo Práticas Científicas em Ensino de Ciências. Foram analisados 44 artigos de periódicos publicados nos últimos dez anos (2010-2019) a partir de quatro bases de dados: ERIC, Scielo, Scopus e Web of Science. Os objetivos foram: I) Identificar publicações envolvendo Práticas Científicas em Ensino de Ciências; II) Sintetizar as características dessas publicações; e III) Analisar criticamente as tendências de pesquisa. Para tanto, foi realizada uma investigação qualitativa norteada pela Análise de Conteúdo de Bardin (2011) e pelo Guia de uma Revisão Sistemática de Okoli (2015). Como resultado, identificou-se que 26 artigos (59,1%) eram da América do Norte e 18 (40,9%) de outros países da Europa, América do Sul, Ásia, Oceania e África, caracterizando as Práticas Científicas como um tema de repercussão internacional. O aumento das pesquisas envolvendo Práticas Científicas, observado em 89% dos estudos que foram publicados na segunda metade da última década, pode ser justificado devido: 1) Ao impacto de documentos norteadores que apresentam grande ênfase nas Práticas Científicas; e 2) A preferência de alguns estudos em utilizar o conceito de aprendizagem tridimensional em vez de "investigação". Dentre as referências mais citadas, estão o NRC (2012) e o NGSS (2013) em 67,6% e 45,9% dos artigos, respectivamente. Também são identificadas lacunas de pesquisa nas Práticas Científicas, como a necessidade de mais pesquisas com um foco central no tema e pesquisas que investiguem a formação inicial de professores. A investigação neste contexto é relevante, uma vez que o ensino de Ciências apoiado em Práticas Científicas é mais facilmente promovido com a instrução intencional na formação inicial de professores.
Palavras-chave: Práticas científicas, NRC, Revisão Sistemática da Literatura, Ensino de Ciências.

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Introduction

In 2012, the National Research Council (NRC) published a conceptual framework for Science Education entitled "A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas". According to the NRC (2012), the framework represents a first step in a process to create new standards in Science Education and can be considered an important step in the strengthening of national documents on Science Education in the United States, which were last developed in the mid-1990s. The framework was developed based on the recognition that, although the existing national documents on scientific content were an important step for science education curriculum, there was still much room for improvement (NRC, 2012).

The document in question: *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, recommends that science education be built 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) Disciplinary Core Ideas in four subject areas.

The relevance of this review can be justified due to the impact of the framework on educational standards across the country. According to the NSTA - National Science Teaching Association, 71% of US students have education standards influenced by the NRC (2012) and 35% of students have already adopted the standards contained in the Next Generation Science Standards (NGSS, 2013), which are based on the NRC (National Science Teaching Association). In this study, we limit ourselves to deepen the understanding of the concept of Scientific Practices (Dimension 1), considering that it has assumed a central role in Science Education and has been the focus of research in several studies not only in the United States (OSBORNE, 2014; BYBEE, 2011; DUSCHL and BYBEE, 2014), but also in other countries, including Brazil, (BROIETTI, NORA & COSTA, 2019).

In this investigation the objectives were to: I) Identify publications involving Scientific Practices in Science Education. II) Synthesize the characteristics of the publications involving Scientific Practices. III) Critically analyze the research trends of publications involving Scientific Practices. When referring to the characteristics of publications the analysis is focused on the: authors, institutions, continents, countries, publication period, research methods, levels of education investigated, fields of knowledge investigated, journals, and main references.

Theoretical foundation

The NRC (2012) presents and describes eight Scientific Practices considered essential for science learning in K-12 education, which are described in Table 1.

Table 1 – Scientific Practices for Science Education

1. Asking questions
Science starts with a question about a phenomenon, such as: "Why is the sky blue?" or “What Causes Cancer?”, and seeks to develop theories that can provide explanatory 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.
2. 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.
3. 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 are used to test existing theories and explanations or to review and develop new theories and explanations.
4. Analyzing and interpreting data
Scientific investigations produce data that must be analyzed. 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 calculated. Technology makes collecting a large amount of data much easier, providing many secondary sources for analysis.
5. 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. Mathematical and computational approaches allow predictions of the behavior of physical systems, along with the confirmation of such predictions. In addition, statistical techniques are invaluable in assessing the significance of patterns or correlations.
6. Constructing explanations
The goal of science is to build theories that can provide explanatory accounts of world phenomena. 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. 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.
7. Engaging in argument from evidence
In science, argumentation is 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 comments offered by others and collaborate with colleagues in the search for the best explanation for the phenomenon investigated.
8. 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. This includes oral information, information in writing, in tables, diagrams, graphs and equations. Science requires the ability to derive meaning from scientific texts (such as journals, internet, conferences and lectures), in order to evaluate scientific knowledge, its validity and integrate this information.

Source: extracted and adapted from NRC (2012)

The NRC (2012) justifies the use of Scientific Practices in Science Education, as the acquisition of skills involved in these Practices supports a better understanding of how scientific knowledge develops. The NRC (2012) highlights the importance of using the eight Practices in combination, as the Practices are not considered a linear sequence of steps that must be developed, but the general objective of the Practices is for students to develop aptitude and ease for using Scientific Practices as resources to support their learning and demonstrate their understanding of Science (NRC, 2012).

Methodological Procedures

According to Fink (2005), the definition of a systematic literature review is: a systematic, explicit and reproducible method for identifying, evaluating and synthesizing the existing body of work produced by researchers and scholars (p. 3, 17). Okoli (2015) presents a guide (Table 2) of eight steps for the development of a systematic literature review.

Table 2 - An eight-step guide for a Systematic Review

1) Identify the objective
2) Develop the protocol and instruct the team
3) Apply a practical screen
4) Search for literature
5) Extract data
6) Assess quality
7) Synthesize studies
8) Write the Review

Source: extracted and adapted from Okoli (2015)

In this review, step 1 consisted of defining the research objectives and their justifications. Step 2 consisted of preparing the protocol for the review (the schedule of research activities) and choosing the methodological and analytical references. Step 3 consisted of applying the filters and defining the exclusion criteria and step 4 consisted of searching the literature. For this review, searches were carried out in four databases: ERIC[1], Scielo[2], Scopus[3] and Web of Science[4]. For all databases, the terms: “scientific practice” and “science education” were searched for. In addition, the following filters were selected: articles and review articles[5]; peer-reviewed journal articles; open access articles; and articles published in the last ten years (2010-2019)[6]. This first search generated a total of 58 results.

In step 5, to systematically extract the relevant data for analysis of the articles, inventories were used. An inventory was filled out for each article in order to permit the identification of the characteristics of the articles involving Scientific Practices in Science Education, as conducted in other similar studies (COSTA, OBARA and BROIETTI, 2020a; SOUSA and VIEIRA, 2019). The inventory model used is shown below in Table 3.

Table 3 - Inventory model used

Code	
Reference in APA	
Authors' Institution	
Journal	
Research method	

[1] https://eric.ed.gov
[2] https://scielo.org
[3] https://www.scopus.com/home.uri
[4] https://clarivate.com/webofsciencegroup/solutions/web-of-science
[5] Term used in Scopus and Web of Science to search for articles that summarize the current state of understanding of a topic.
[6] This filter was not available in ERIC, so we had to filter this criterion manually.

Objective(s)	
Level of Education investigated	
Field (Chemistry, Physics, Biology) investigated	
Use of the term Scientific Practice	
Theoretical references of Scientific Practice	

Source: the authors

To fill out the item "Use of the term Scientific Practice" we searched for the expression "practice" in the body of the article; read all the paragraphs that contained the term; and transcribed the fragments into the inventory. To fill out the item: “Theoretical references of Scientific Practice”, the item “Use of the term Scientific Practice” was read and all references that mentioned the term were transcribed. The term “scientific practice” was also searched for in the bibliographic references of the articles and the respective references were transcribed. This procedure ensured that references of Scientific Practice that had and did not have the term in the title of the articles were transcribed, as performed in other similar studies for other themes (critical thinking) in Science Education (COSTA, OBARA & BROIETTI, 2020b).

In step 6, to assess the quality of the inventories, a first reading was done and after this process 14 articles were excluded for different reasons (articles from other areas, duplicated articles and no mention of the Practices). Thus, the *corpus* of this research was composed of the inventories of 44 articles. In step 7, Okoli (2015) recommends the use of appropriate techniques, whether qualitative or quantitative. In the present study, Content Analysis proposed by Bardin (2011) was used.

In this study, Content Analysis comprised of: 1) the first contact with the articles, that is, the first reading, as well as the extraction of information to fill out the inventories; 2) the coding of articles from A01-A44; the grouping of articles according to similar characteristics of publications; and 3) the presentation of the results of the categorizations and similarities found between articles involving Scientific Practices in Science Education. Thus, step 7 involved the three phases of Bardin's Content Analysis (2011). Step 8, consisted of writing this review which sought to synthesize the available material and offer an academic critique of the analyzed studies.

Results and Discussions

Table 4 shows the codification of the 44 articles analyzed in this research. The first column corresponds to the code and the second column to the bibliographic reference of the article. The discussions in this section were conducted using the article codes.

Table 4 - Codification of the 44 articles analyzed in this research

Code	Article
A01	Houseal, A. K. (2016). A Visual Representation of Three Dimensional Learning: A Model for Understanding the Power of the Framework and the NGSS. *Electronic Journal of Science Education*, *20*(9), 1-7.
A02	Valenti, S. S., Masnick, A. M., Cox, B. D., & Osman, C. J. (2016). Adolescents' and Emerging Adults' Implicit Attitudes about STEM Careers:" Science Is Not Creative". *Science Education International*, *27*(1), 40-58.
A03	Rosenberg, J. M., & Lawson, M. A. (2019). An investigation of students' use of a computational science simulation in an online high school physics class. *Education Sciences*, *9*(1), 49.
A04	Rodriguez, B., Jaramillo, V., Wolf, V., Bautista, E., Portillo, J., Brouke, A., ... & Ashcroft, J. (2018). Contextualizing technology in the classroom via remote access: using space exploration themes and scanning electron microscopy as tools to promote engagement in geology/chemistry experiments. *JOTSE: Journal of technology and science education*, *8*(1), 86-95.
A05	Nicolaou, C. (2015). Elementary School Students' Emotions When Exploring an Authentic Socio-Scientific Issue through the Use of Models. *Science Education International*, *26*(2), 240-259.
A06	Vick, M. E., & Garvey, M. P. (2016). Environmental Science and Engineering Merit Badges: An Exploratory Case Study of a Non-Formal Science Education Program and the US Scientific and Engineering Practices. *International Journal of Environmental and Science Education*, *11*(18), 11675-11698.
A07	Buxner, S. R. (2014). Exploring how research experiences for teachers changes their understandings of the nature of science and scientific inquiry. *Journal of Astronomy & Earth Sciences Education (JAESE)*, *1*(1), 53-68.
A08	Lunde, T., Rundgren, S. N. C., & Drechsler, M. (2016). Exploring the negotiation of the meaning of laboratory work in a continuous professional development program for lower secondary teachers. *Electronic Journal of Science Education*, *20*(8), 26-48.
A09	Buck, G. A., Akerson, V. L., Quigley, C. F., & Weiland, I. S. (2014). Exploring the Potential of Using Explicit Reflective Instruction through Contextualized and Decontextualized Approaches to Teach First-Grade African American Girls the Practices of Science. *Electronic Journal of Science Education*, *18*(6).
A10	Gunning, A. M., Marrero, M. E., & Morell, Z. (2016). Family Learning Opportunities in Engineering and Science. *Electronic Journal of Science Education*, *20*(7), 1-25.
A11	Palma, C., Plummer, J., Rubin, K., Flarend, A., Ong, Y. S., McDonald, S., ... & Furman, T. (2017). Have Astronauts Visited Neptune? Student Ideas about How Scientists Study the Solar System. *Journal of Astronomy & Earth Sciences Education*, *4*(1), 63-74.
A12	Tractenberg, R. E. (2017). How the Mastery Rubric for Statistical Literacy can generate actionable evidence about statistical and quantitative learning outcomes. *Education Sciences*, *7*(1), 3.
A13	Riedinger, K., & Taylor, A. (2016). "I Could See Myself as a Scientist": The Potential of Out-of-School Time Programs to Influence Girls' Identities in Science. *Afterschool Matters*, *23*, 1-7.
A14	Ayar, M. C., & Yalvac, B. (2016). Lessons learned: authenticity, interdisciplinarity, and mentoring for STEM learning environments. *International Journal of Education in Mathematics, Science and Technology*, *4*(1), 30-43.
A15	Brownstein, E. M., & Horvath, L. (2016). Next Generation Science Standards and edTPA: Evidence of Science and Engineering Practices. *Online Submission*, *20*(4), 44-62.
A16	Bardeen, M., Wayne, M., & Young, M. J. (2018). Quarknet: A unique and transformative physics education program. *Education Sciences*, *8*(1), 17.
A17	Koomen, M. H., Blair, R., Young-Isebrand, E., & Oberhauser, K. S. (2014). Science professional development with teachers: Nurturing the scientist within. *Electronic Journal of Science Education*, *18*(6).
A18	Bogar, Y. (2019). Synthesis Study on Argumentation in Science Education. *International Education Studies*, *12*(9), 1-14.

A19	Engels, M., Miller, B., Squires, A., Jennewein, J. S., & Eitel, K. (2019). The Confluence Approach: Developing scientific literacy through project-based learning and place-based education in the context of NGSS. *Electronic Journal of Science Education*, *23*(3).
A20	Gotwals, A. W., Hokayem, H., Song, T., & Songer, N. B. (2013). The Role of Disciplinary Core Ideas and Practices in the Complexity of Large-Scale Assessment Items. *Electronic Journal of Science Education*, *17*(1), n1.
A21	Carpenter, S. L. (2015). Undergraduates' perceived gains and ideas about teaching and learning science from participating in science education outreach programs. *Journal of Higher Education Outreach and Engagement*, *19*(3), 113-146.
A22	Erenler, S., & Cetin, P. S. (2019). Utilizing Argument-Driven-Inquiry to Develop Pre-Service Teachers' Metacognitive Awareness and Writing Skills. *International Journal of Research in Education and Science*, *5*(2), 628-638.
A23	Iwuanyanwu, P. N. (2019). What We Teach in Science, and What Learners Learn: A Gap That Needs Bridging. *Online Submission*, *4*(2).
A24	Brandão, R. V., Araujo, I. S., Veit, E. A., & da Silveira, F. L. (2011). Validación de un cuestionario para investigar concepciones de profesores sobre ciencia y modelado científico en el contexto de la física. *Revista electrónica de investigación en educación en ciencias*, *6*(1), 43-61.
A25	Underwood, S. M., Posey, L. A., Herrington, D. G., Carmel, J. H., & Cooper, M. M. (2018). Adapting assessment tasks to support three-dimensional learning. *Journal of Chemical Education*, *95*(2), 207-217.
A26	Reed, J. J., Brandriet, A. R., & Holme, T. A. (2017). Analyzing the role of science practices in ACS exam items. *Journal of Chemical Education*, *94*(1), 3-10.
A27	Barcellos, L. S., & Coelho, G. R. (2019). Uma Análise das Interações Discursivas em uma Aula Investigativa de Ciências nos Anos Iniciais do Ensino Fundamental Sobre Medidas Protetivas Contra a Exposição ao Sol. *Investigações em Ensino de Ciências*, *24*(1).
A28	Rowland, S., Hardy, J., Colthorpe, K., Pedwell, R., & Kuchel, L. (2018). CLIPS (Communication Learning in Practice for Scientists): A New Online Resource Leverages Assessment to Help Students and Academics Improve Science Communication. *Journal of microbiology & biology education*, *19*(1).
A29	Elliott, K. C., Cheruvelil, K. S., Montgomery, G. M., & Soranno, P. A. (2016). Conceptions of good science in our data-rich world. *BioScience*, *66*(10), 880-889.
A30	Boisselle, L. N. (2016). Decolonizing science and science education in a postcolonial space (Trinidad, a developing Caribbean nation, illustrates). *Sage Open*, *6*(1).
A31	Odden, T. O. B., & Russ, R. S. (2019). Defining sensemaking: Bringing clarity to a fragmented theoretical construct. *Science Education*, *103*(1), 187-205.
A32	Prins, G. T., Bulte, A. M., & Pilot, A. (2018). Designing context-based teaching materials by transforming authentic scientific modelling practices in chemistry. *International Journal of Science Education*, *40*(10), 1108-1135.
A33	Oliva, J. M. (2019). Distintas acepciones para la idea de modelización en la enseñanza de las ciencias.
A34	López, V., Grimalt-Álvaro, C., & Couso, D. (2018). ¿ Cómo ayuda la Pizarra Digital Interactiva (PDI) a la hora de promover prácticas de indagación y modelización en el aula de ciencias?. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, *15*(3), 330201-330215.
A35	Scalise, K., & Clarke-Midura, J. (2018). The many faces of scientific inquiry: Effectively measuring what students do and not only what they say. *Journal of Research in Science Teaching*, *55*(10), 1469-1496.
A36	Evagorou, M., Erduran, S., & Mäntylä, T. (2015). The role of visual representations in scientific practices: from conceptual understanding and knowledge generation to 'seeing'how science works. *International Journal of STEM Education*, *2*(1), 11.
A37	Koomen, M. H., Rodriguez, E., Hoffman, A., Petersen, C., & Oberhauser, K. (2018). Authentic science with citizen science and student-driven science fair projects. *Science Education*, *102*(3), 593-644.
A38	Bierema, A. M. K., Schwarz, C. V., & Stoltzfus, J. R. (2017). Engaging undergraduate biology students in scientific modeling: Analysis of group interactions, sense-making, and justification. *CBE—Life Sciences Education*, *16*(4), ar68.
A39	Bargiela, I. M., Mauriz, B. P., & Anaya, P. B. (2018). Las prácticas científicas en infantil: una aproximación al análisis del currículum y planes de formación del profesorado de

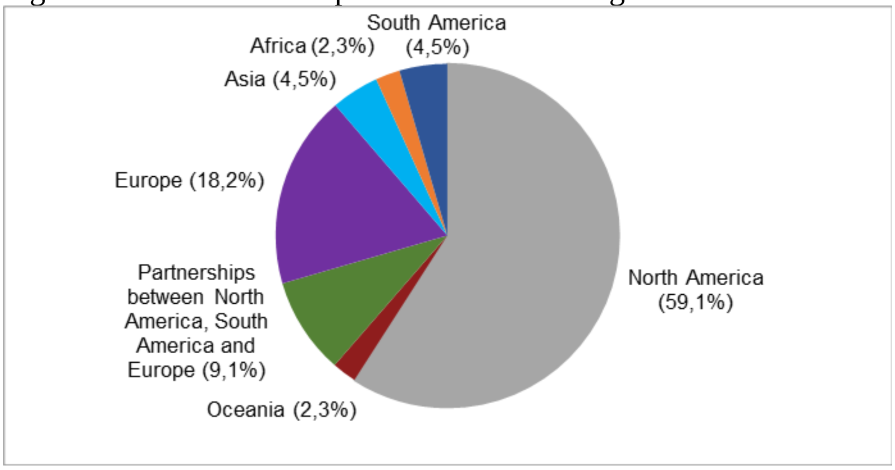
	Galicia. *Enseñanza de las ciencias: revista de investigación y experiencias didácticas*, *36*(1), 7-23.
A40	Kind, P., & Osborne, J. (2017). Styles of scientific reasoning: A cultural rationale for science education?. *Science Education*, *101*(1), 8-31.
A41	Roberts, R., & Johnson, P. (2015). Understanding the quality of data: a concept map for 'the thinking behind the doing'in scientific practice. *The Curriculum Journal*, *26*(3), 345-369.
A42	Dunlop, L., & Veneu, F. (2019). Controversies in Science. *Science & Education*, *28*(6-7), 689-710.
A43	Lombardi, D., Bickel, E. S., Bailey, J. M., & Burrell, S. (2018). High school students' evaluations, plausibility (re) appraisals, and knowledge about topics in Earth science. *Science Education*, *102*(1), 153-177.
A44	Wyner, Y., & Doherty, J. H. (2017). Developing a learning progression for three-dimensional learning of the patterns of evolution. *Science Education*, *101*(5), 787-817.

Source: the authors

Regarding the authors who published articles involving Scientific Practices, the following stand out: Michele Hollingsworth Koomen and Karen Suzanne Oberhauser, each with 2 articles. The other authors presented only 1 article each in the *corpus*. Regarding the institutions that most published articles involving Scientific Practices, the following can be highlighted: Michigan State University, in the United States, which contributed with 4 articles (9.1%) and then the University of Wisconsin, in the United States, with 3 articles (6, 8%).

Regarding the continents of the publications, Figure 1 shows the distribution of publications according to the continents.

Figure 1 - Distribution of publications according to continents



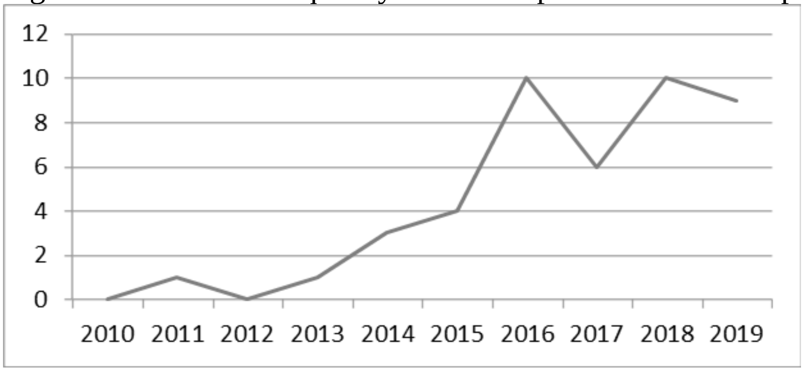
Source: the authors

It is noteworthy that although 59.1% of the articles are from North America, 40.9% involved other countries in Europe, South America, Asia, Oceania, and Africa, characterizing Scientific Practices as a topic of international repercussion. Regarding the countries of publications, 26 articles (59.1%) were from institutions in the United States; 3 articles (6.8%) were from institutions in Spain; 2 articles (4.5%) from institutions in

England; 2 articles (4.5%) from institutions in Brazil; and 2 articles (4.5%) from institutions in Turkey. The following countries also appeared in 1 article each: Holland, Australia, South Africa, Cyprus, and Sweden, corresponding to 2.3% each. Collaborations between different countries were also noted. 1 article (2.3%) from an institution in Norway with one from the United States; 1 article (2.3%) from an institution in the United States with one in Brazil; 1 article (2.3%) from an institution in England with one from the United States; and 1 article (2.3%) from an institution in Cyprus with one from England and Finland.

Regarding the frequency of articles published, Figure 2 is presented.

Figure 2 – Absolute frequency of articles published over the past decade



Source: the authors

The years 2016 and 2018 can be highlighted with the largest number of publications involving the theme - Scientific Practices, with 20 articles (45.4%) published in those years. There has been a growing interest in research involving Scientific Practices in recent years, since 39 articles (89%) were published between 2015-2019. We believe that NRC (2012) and NGSS (2013) contributed to the increase in interest in this topic due to the influence of these documents in science curriculum. According to the NRC (2012):

> [...]the term “inquiry,” extensively referred to in previous standards documents, has been interpreted over time in many different ways throughout the science education community, part of our intent in articulating the practices in Dimension 1 is to better specify what is meant by inquiry in science and the range of cognitive, social, and physical practices that it requires. As in all inquiry-based approaches to science teaching, our expectation is that students will themselves engage in the practices and not merely learn about them secondhand (NRC, 2012, p. 30).

> [...] attempts to develop the idea that science should be taught through a process of inquiry have been hampered by the lack of a

> commonly accepted definition of its constituent elements. Such ambiguity results in widely divergente pedagogic objectives [18]—an outcome that is counterproductive to the goal of common standards (NRC, p. 44).

Thus, the concept of Scientific Practice is shown as a way to better clarify what Science Teaching is and how it can be carried out by investigation, due to the ambiguity caused by the term "inquiry" in previous guiding documents and the lack of clarity that teachers had with the concept. Authors such as Duschl & Bybee (2014) and Osborne (2014) mention that the new generation science standards are, among other changes, shifting from scientific investigation (inquiry) to the inclusion of Scientific Practices.

Regarding the research methods, 11 groups were identified, organized in Table 5.

Table 5 - Research methods of the articles

Method	**Number of articles (percentage)**
Not specified	**14 (31,8%)**
Qualitative research (Merriam, 2009; Denzin & Lincoln, 2011; Creswell, 2003).	7 (15,9%)
Case study (Yin, 2009; Yin, 2014)	2 (4,5%)
Participatory action research study (Kemmis & McTaggart, 2000)	1 (2,3%)
Collective case study approach	1 (2,3%)
Mixed methods research (Creswell & Plano Clark, 2007; Burke & Onwuegbuzie, 2004)	4 (9,1%)
Qualitative and interventional research	1 (2,3%)
Iterative design	1 (2,3%)
Theoretical research	11 (25%)
Literature review	1 (2,3%)
Single group pre/post test design (Gay & Airasian, 2000)	1 (2,3%)

Source: the authors

It is noticed that a large part of the articles (31.8%) did not explicitly mention the method used. These articles usually described the steps performed and reported the tools used. When these articles held a discussion of a theoretical nature, without empirical results, they were allocated to "Theoretical research". When these articles carried out research with empirical results and did not specify the research method used, these were allocated to the "Not specified" group. Regarding the levels of education investigated, 13 groups were identified (Table 6). The educational levels presented were organized according to the educational system of the United States. Thus, the terms presented differently in international articles were converted to maintain the standard.

Table 6 - Education levels emerging from articles

Education levels	**Number of articles (percentage)**
Early Childhood Education	2 (4,5%)

Elementary School (1st-5th grade)	2 (4,5%)
Middle School (6th-8th grade)	5 (11,4%)
Middle School and High School	1 (2,3%)
High School (9th-12th grade)	3 (6,8%)
High School and Undergraduate Education	1 (2,3%)
Pre University[7]	1 (2,3%)
Undergraduate Education	4 (9,1%)
Pre-service Teacher Education	1 (2,3%)
Unspecified	**14 (31,8%)**
K-12	3 (6,8%)
In-Service Teacher Education	6 (13,6%)
Middle School, Undergraduate and Graduate Education	1 (2,3%)

Source: the authors

Most of the articles, 14 articles (31.8%), did not specify the education level investigated. We also noticed that many articles investigated: In-service teachers (13.6%); Middle school (11.4%); and Undergraduate Education (9.1%). On the other hand, only 1 article (2.3%) investigated Pre-service teachers. We consider this data relevant, since the teaching of Science supported by Scientific Practices is more easily promoted with intentional instruction in the initial training of teachers (NRC, 2013; NRC, 2012).

Regarding the fields of knowledge, 14 groups were identified (Table 7).

Table 7 - Knowledge fields emerging from articles

Field	**Number of articles (percentage)**
Science	**25 (56,8%)**
Physics	3 (6,8%)
Not specified	1 (2,3%)
Astronomy	1 (2,3%)
Astronomy and Science	1 (2,3%)
Environmental Science	1 (2,3%)
Geology and Chemistry	1 (2,3%)
Physical Sciences and Biology	1 (2,3%)
Physics, Biology and Chemistry	2 (4,5%)
Biology	3 (6,8%)
Science, Biology, Physics and Chemistry	1 (2,3%)
Science, Biology, Environmental Science and Physics	1 (2,3%)
Chemistry	2 (4,5%)
Earth Science	1 (2,3%)

Source: the authors

Through Table 7 it is noted that most of the articles belonged to Science (56.8%). In relation to specific subjects, 2 Chemistry articles (4.5%); 3 Biology articles (6.8%); and 3 Physics articles (6.8%) were identified. Regarding the journals in which the articles were

[7] Term used in the article.

published the journals with the largest number of articles were: *Electronic Journal of Science Education*, with 8 articles (18,2%); *Science Education*, with 5 articles (11,4%); and *Education Sciences*, with 3 articles (6,8%).

Regarding the references to support the discussions on Scientific Practices, 2 categories were identified, shown in Table 8.

Table 8 – References of Scientific Practices presented in the articles

Category	Description	Articles
R1	Articles that do not mention references on Scientific Practices to support the discussions.	A02, A04, A05, A12, A21, A28, A30
R2	Articles that mention references on Scientific Practices to support the discussions.	A01, A03, A06, A07, A08, A09, A10, A11, A13, A14, A15, A16, A17, A18, A19, A20, A22, A23, A24, A25, A26, A27, A29, A31, A32, A33, A34, A35, A36, A37, A38, A39, A40, A41, A42, A43, A44

Source: the authors

It is noticed that most articles (84%) are based on references that discuss Scientific Practices. This is relevant, as Scientific Practice is not treated as a vague term in these articles (R2). These articles define the term Scientific Practice and present considerations by other authors to enrich the discussions. Table 9 presents the most cited references.

Table 9 – Most cited references of Scientific Practice

Theoretical references	Cited in
National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.[8]	A01, A03, A06, A07, A09, A10, A11, A15, A17, A19, A20, A23, A25, A26, A31, A34, A35, A36, A37, A38, A39, A40, A41, A43, A44
NGSS Lead States. (2013). *Next Generation Science Standards: For States, by States*. National Academies Press: Washington, DC, USA	A03, A06, A07, A10, A11, A14, A15, A16, A17, A19, A25, A26, A35, A37, A41, A43, A44
Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. B., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*, *53*(7), 1082– 1112.[9]	A03, A37, A38
National Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.	A07, A19, A44
Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education*, *92*(3), 404-423.	A08, A18, A37
White, B.Y.; Frederiksen, J.R. (1998) Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, *16*, 3–118.	A03, A35
Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science	A08, A38

[8] The same reference from 2011 was also considered
[9] The same reference from 2015 was also considered

investigations. *Science Education, 92*(5), 941-967.	
Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., ... & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(6), 632–654.	A03, A38
Bybee, R. W. (2011). Scientific and engineering practices in K–12 classrooms: Understanding a framework for K–12 science education. *The Science Teacher, 78*(9), 34–40.	A09, A19
Minner, D. D., Levy, A. J., & Century, J. (2010), Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*, 474–496.	A10, A35
Eberbach, C., & Crowley, K. (2009). From everyday to scientific observation: How children learn to observe the biologist's world. *Review of Educational Research, 79*(1), 39-68.	A11, A44
National Research Council (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, D.C.: National Academies Press.	A11, A23
Latour, B., & Woolgar, S. (1986). Laboratory life: The construction of scientific facts. Princeton, NJ: Princeton University Press.[10]	A14, A36
Duschl, R. A., & Bybee, R. W. (2014). Planning and carrying out investigations: An entry to learning and to teacher professional development around NGSS science and engineering practices. *International Journal of STEM Education, 1*(1), 1-9.	A15, A36
Forbes, C. T., Biggers, M., & Zagori, L. (2013). Investigating essential characteristics of scientific practices in elementary science learning environments: The practices of science observation protocol (P-SOP). *School Science and Mathematics, 113*(4), 180-190.	A17, A37
Reiser, B. J., Berland, L. K., & Kenyon, L. (2012). Engaging students in scientific practices of explanation and argumentation: Understanding A framework for K-12 science education. *Science Teacher, 79*(4), 34–39.	A31, A39
Prins, G. T., Bulte, A. M. W., Van Driel, J. H., & Pilot, A. (2009). Students' involvement in authentic modelling practices as contexts in chemistry education. *Research in Science Education, 39*(5), 681–700.	A32, A33
Kelly, G. J. (2008). Inquiry, activity, and epistemic practice. In R. Duschl & R. Grandy (Eds.), Teaching scientific inquiry: Recommendations for research and implementation (pp. 99-117– 288-291). Rotterdam: Sense Publishers.	A32, A39
Osborne, J. (2014). Teaching scientific practices: meeting the challenge of change. *Journal of Science Teacher Education, 25*(2), 177–196.	A34, A36

Source: the authors

The references: NRC (2012) and NGSS (2013) were the most cited to support the concept of Scientific Practices, present in 67.6% and 45.9% of articles, respectively. Through the large number of articles that cited these references, is it possible to note the influence of these documents in research involving Scientific Practices. It is also important to highlight the references published before 2012 in Table 9, as they already discussed the concept of Scientific Practice before the main document of the NRC (2012).

Final considerations

[10] The same reference from 1979 was also considered.

In the *corpus*, there was only 1 article (2.3%) that investigated Scientific Practices and Pre-Service Teachers. More research that focuses on Scientific Practices in Pre-Service Teacher Education is needed. Research in this sense could help understand how these Practices have been articulated in the training of future science teachers and if intentional instruction towards Scientific Practices is being developed. Research investigating the relationship between Scientific Practices and Pre-service Teacher Education is also relevant, since Science teaching supported by Scientific Practices is more easily promoted with intentional instruction in the initial training of teachers.

Among the articles analyzed, only 38.6% presented the term Scientific Practices in research objectives and problems, despite having the term in the abstract. Thus more research which has Scientific Practices as its central focus is still needed. The articles which investigated Scientific Practices more in-depth (A01, A06, A09, A12, A17, A20, A25, A26, A28, A29, A33, A34, A37, A38, A39, A41, A44) can serve as a basis reading for researchers who wish to develop further research on the subject.

The list of countries which investigated Scientific Practices shows that other countries outside the United States have also given great attention to Scientific Practices, characterizing Scientific Practices as an international research theme in the area of Science Education.

Interest in research involving Scientific Practices has increased in recent years, as 89% of studies were published in the second half of the last decade. This fact can be justified due to: 1) The impact of the NRC (2012) and NGSS (2013) documents on Science Education as a whole, due to the importance given to Scientific Practices in these documents; and 2) The preference of some studies to use the concept of three-dimensional learning (Scientific Practices, Cross-cutting Concepts, and Central Ideas) instead of “inquiry” to better clarify what science teaching is and how it can be done. Research regarding other countries' Science Education curriculums could help better understand if Scientific Practices have been given similar emphasis.

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