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Systematic Review

Scientific Method's Application Contexts for the Development and Evaluation of Research Skills in Higher-Education Learners

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Abstract: The evolution of curricula in recent decades has given rise to multiple ways of teaching the task of experimental science, through which research skills are developed. In this learning gain process, teaching the systematized steps of the scientific method has been of invaluable help. In this study, we wanted to determine under what contexts of the last century the knowledge of the scientific method has encouraged the development of research skills in higher education learners. Through a literature review yielding nineteen empirical articles in the SCOPUS and Web of Science databases between 2000 and 2022, it was found that the scientific method is rarely mentioned and is more often referred to as a set of steps or structures to solve a problem, a challenge, or to carry out an investigation or an assigned task. Problem-solving and critical thinking were the two most-cited skills developed through the knowledge and practice of the scientific method. There are skills developed in theoretical classes and others that can be developed in practical courses such as laboratories or field work. A gap was found in the literature on using the scientific method and developing research skills in learners of non-science, technology, engineering, and mathematics (STEM) fields. The findings of this review lead studies to determine and compare whether effectively teaching students the scientific method improves their understanding and development of research skills in STEM and non-STEM areas.

Keywords: challenge-based learning; critical thinking; educational innovation; higher education; problem-solving; science; technology; engineering; mathematics; STEM

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1. Introduction

According to the National Foundation for Educational Research in the United Kingdom, among the fastest-growing occupational sectors are health, personal and social care, education, sales, business development, creative and digital design, green economy, communication, information, and the natural and applied sciences [1]. In addition, problem-solving, critical thinking, analysis, and communication are the primary transferable skills (which can be implemented transversally in different careers or jobs), considered essential for the labor demand of the future. The fact that a student possesses these skills means they can find solutions to challenges, synthesize and interpret information, and effectively communicate their results in the main sectorial drivers of the economies worldwide [1]. Some students may take extracurricular classes, MOOCs, or online courses to develop such skills. However, of the more than 100 million people using Coursera, there is a significant gap between the number of students (between 20 and 40% in exceptional cases, but some others in less than 10%) who have reached the skill proficiency required by the megatrend jobs' employers (Data Scientist, Data Analyst, Software Engineer, Machine Learning Engineer, and Marketing Specialist), and those students who have not developed the skill proficiency. Mathematics, data visualization, programming, probability, and statistics are the less developed skills [2].

The same has happened in research skills, mainly due to the COVID-19 pandemic disrupting laboratory practices and preventing graduates from fully developing them [3]. Research skills have been defined as "actions or tasks that can be taught, practiced, and performed to establish facts, postulate new ideas, test ideas to collect data, and analyze data to draw conclusions" [4]. Multiple frameworks define the research skills or competencies that higher-education learners must develop [5]. Intellectual and practical skills, including inquiry and analysis, critical and creative thinking, written and oral communication, quantitative literacy, information literacy, teamwork, and problem-solving, are essential outcomes for the Association of American Colleges and Universities. In Table 1, there is a list of some associations that determine the type of research skills and competencies students must develop during their careers.

Table 1. Definition of research skills by national and international organizations.

Institution/Organization	Research Skills/Competences
United Nations Educational, Scientific and Cultural Organization (UNESCO) https://unesdoc.unesco.org (accessed on 28 May 2022)	Cognitive Information processing (data interpretation and analysis) Problem-solving Engineering thinking Scientific investigation Computational thinking Design thinking, creativity, and innovation
Organization for Economic Co-operation and Development (OECD) https://www.oecd.org/education/2030-project/ (accessed on 28 May 2022)	Critical thinking Problem-solving Learning to learn Co-cooperative skills
National Research Council Framework (USA) https://www.cgcs.org/domain/125 (accessed on 28 May 2022)	Asking questions and defining problems Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics Computational thinking Constructing explanations Designing solutions Engaging in arguments from evidence Obtaining, evaluating, and communicating information
The National Science Foundation (USA) https://www.nsf.gov/ (accessed on 29 May 2022) Global STEM alliances (USA) https://www.nyas.org/ (accessed on 29 May 2022)	Problem-solving Creativity Thinking analysis Teamwork Independent thinking Initiative Digital literacy
Next generation Science Standards (USA) https://www.nextgenscience.org/framework-k-12-science-education (accessed on 29 May 2022)	Asking questions and defining problems Developing and using models Planning and carrying out investigations Analyzing and interpreting data using mathematical and computational thinking Constructing explanations and designing solutions Engaging in arguments using evidence Obtaining, evaluating, and communicating information
Biological and Biotechnological Science Research Council (UK) https://www.ukri.org/councils/bbsrc (accessed on 29 May 2022)	Innovation Technology development integrated information and resources Data integration and modeling Research translation and application

Tests for measuring research skills and abilities have been developed [6]. Increased data availability has enhanced this process through digital technologies [7]. However, how can it be ensured that higher-education learners develop these skills during their careers? Authors with constructivist tendencies have mentioned that this is achieved by problematizing situations and favor the student's scientific spirit and capacity for reflection and creativity [8]. Educational approaches such as inquiry-, problem-, and challenge-based learning [8–10] emerge as useful mediating didactics [11] in all areas, including the social sciences [12]. However, not much of the corresponding literature on these approaches requires a sequence or methodology that makes the studies replicable. Instead, the verification of hypotheses and theories today is relegated to empiricism, solutionism, and problem prevention [13]. The COVID-19 pandemic has shown that the scientific methodology that has been addressed has been inadequate, revealing false assumptions and gaps in areas where knowledge is complex and changing [13]. Thus, a process of systematization of the research methodology used for the studies planned and developed in schools and universities is required [7,14].

In this regard, using the scientific method has been helpful, providing students with advocacy to observe, hypothesize, experiment, and draw conclusions. It has been reported that it increases student engagement and motivation to achieve objectives [15] and enhances the student learning process in educational laboratory environments [16]. The scientific method is "the general procedure of science applied in the knowledge gain process, regardless of the topic under study" [17]. It was once considered a learning tool in higher education to develop competencies. The scientific method foresees transversal application since it can be implemented in various areas of study, from services and manufacturing to higher education [18,19]. In its most complex forms, one can use tools such as machine learning to find improvements in any process [18]. The scientific method consists of strategies to obtain information about a problem at the theoretical (the analysis of scientific and methodological literature), experimental (experiments and observation), and statistical (the processing of results) levels [20,21]. It helps solve problems and challenges. Authors suggest that transversal and disciplinary competencies are developed when students realize that the scientific method leads them through the scientific process [22]. It has also been found that the teacher's stance on the scientific method influences the development of research skills in their students [23].

Problem-solving is a research skill associated with the learning process based on the scientific method, especially in science, technology, engineering, and mathematics (STEM) careers [24–26]. However, research skills can be developed in other disciplines [27]. Laboratory or theoretical classes have been crucial for practicing and developing these skills [28]. In the study by Hidalgo et al. [29], in which a problem-based approach was addressed with materials available in a digital format, it was found that medical students preferred practical classes and seminars instead of theoretical classes when they required documentation and scientific method skills. It also has been found that students in their final year are perceived to have medium to high levels of some research skills (writing and data collection and qualitative analysis) in several university contexts. By contrast, other skills (such as bibliographic searching, referencing, and quantitative analysis) are less perceived [30].

The motivation for this work is that, as professionals in science and education, we know that the scientific method is one of the pillars for developing scientific skills. However, two events have modified the perception of the use of the scientific method. The first event is the increasingly intense use of digital tools and data banks and the help or risk that this means for research. On the other hand, the COVID-19 pandemic brought a setback in the development and application of disciplinary research skills applied to science courses as laboratories were closed for almost two years. In the gradual, conscious return to schools, attempts have been made to open new educational schemes for applied disciplinary skills, allowing students to choose between theoretical and practical classes to develop and practice these investigative skills. However, the quantity and quality of the impact of this transition have yet to be examined.

Therefore, we performed a literature scope to provide insight into how the scientific method is applied in educational research and its relation to developing research skills in higher education during the last twenty years. From here, we propose the following research questions. RQ1—What is the association between the scientific method and the development of research skills by higher education learners? RQ2—Under what context (theoretical or laboratory courses) is applying the scientific method helpful in developing research skills?

2. Methodology

This work was conducted with an attempt to consider the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model methodology [31]. However, based on the work of Sousa and Costa [32], in which two types of methods can be employed, this research was framed as a scoping review since "it enables relatively swift coverage of a field, does not require quality assessment of each article selected and does not emphasize the synthesis of results [33]," and a rapid review, since some shortcuts to the PRISMA were taken [34]. The process for this review included the steps suggested by [35]: (1) formulate a research question, (2) search databases, (3) identify inclusion/exclusion criteria, (4) select studies, (5) extract data and perform an analysis, (6) provide a summary and an interpretation of findings, and (7) write the review report.

2.1. Search on Databases

Our literature review was carried out in July 2022. The search was limited to peer-reviewed articles or conference papers found through the SCOPUS and Web of Knowledge (WoS) databases. Keywords were previously identified and used in different combinations by utilizing "Boolean" operators (AND, OR). The search string terms included core concepts aligned with our research topic and questions. A search string was created by compiling Boolean and simple operators with parentheses. The search string used was (ALL ("research skills" AND "scientific method") OR ALL ("research competency" AND "scientific method") OR ALL ("research competencies" AND "Scientific method") AND ALL ("higher education"). The database search was adjusted based on the inclusion or exclusion criteria.

2.2. Inclusion/Exclusion Criteria

Specific criteria were established to help us select and include relevant studies to our research topic and excluded the studies that failed to meet some necessary conditions. The inclusion and exclusion criteria are presented in Table 2.

Table 2. Inclusion and exclusion criteria in the systematic review.

Inclusion Criteria	Exclusion Criteria
1. The article must contain information about the scientific method and its relation to developed research skills.	1. The study does not mention the scientific method elements.
2. The study was conducted in an educational learning environment (higher education).	2. The study only includes opinions about scientific method practice.
3. The study is related to any content area (chemistry, physics, biology, health education, natural sciences).	3. The study is not accessible or only published as an abstract.
4. The article is a peer-reviewed or conference paper.	4. The study is not written in the English language.
5. The article was published from 2000 to 2022.	5. The study is not empirical.

2.3. Review Process

The initial search results in all databases produced a total of 55 articles (43 in SCOPUS and 12 in WoS). Based on duplicates, publishing date, title review, relevance, abstract review, and access, 23 articles were excluded. The remaining 32 were scoped for further information. A total of 5 studies did not include the specific topics and were excluded.

The remaining 27 articles were carefully and thoroughly reviewed in relevance to our criteria and research questions, leaving 8 articles out of this study. A thematic analysis procedure was followed during this process. Each participating author in this publication kept separate notes and read each article multiple times to properly comprehend its content, methods, and displayed findings. All the information was then compared and discussed, yielding nineteen articles, which comprised the final dataset for the systematic review. The result of the PRISMA review protocol is depicted in Figure 1.

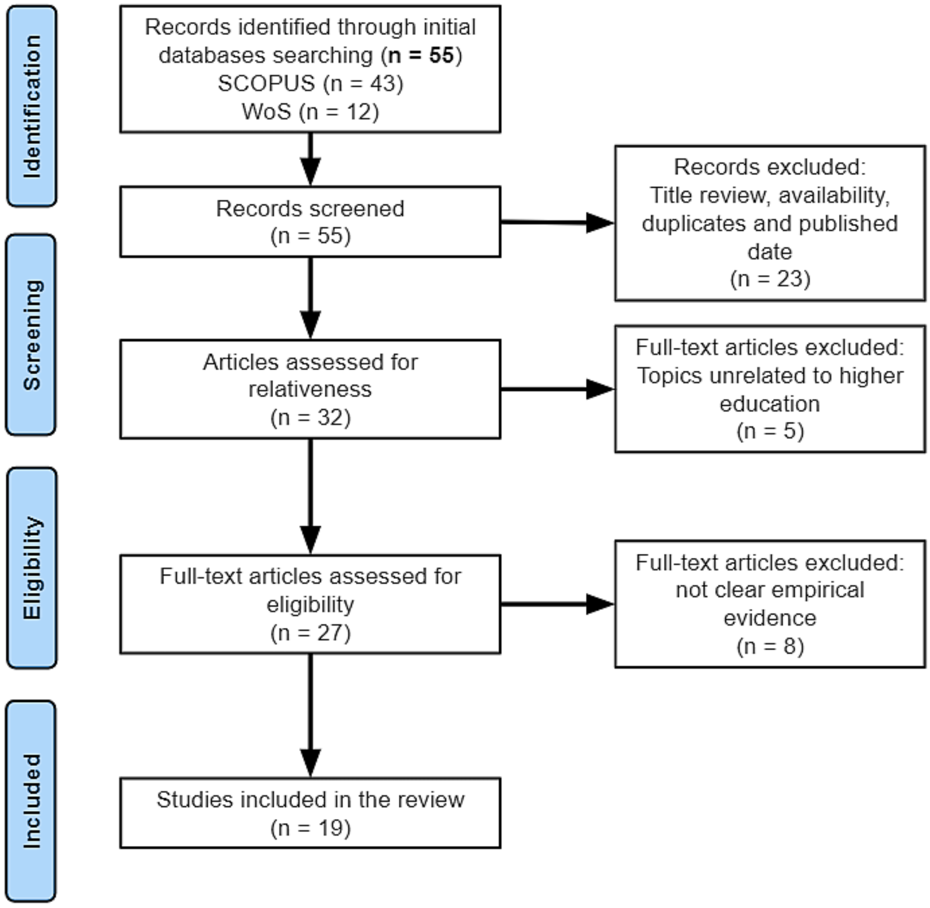

Figure 1. Flowchart of the selection process based on the PRISMA method.

2.4. Data Extraction and Analysis

The 19 articles were further analyzed to provide aggregated data findings concerning the research questions. A triangulation process was followed [36]. A systematic keyword search was used to collect data across all studies while preserving their credibility (data not shown). To ensure the convergence and verification of our findings, we lastly conducted a document analysis, completing our triangulation procedure. Information was extracted from each article regarding (a) country of origin, (b) source (journal or conference), (c) content area or discipline, (d) educational context, (e) methodology and assessment tools, (f) number of impacted students/reviewed studies, and (g) skills developed.

2.5. Risk of Bias

Scoping reviews are "generally conducted to provide an overview of the existing evidence regardless of methodological quality or risk of bias" [37]. However, this research has potential biases: the disregard of articles that do not explicitly mention the scientific method or concepts related to it, and the search equation not including all terms associated with the scientific method in all its components. These are two sources of errors in systematic reviews. One is a systematic error, which arises from specific limitations of the design of a study. The second is a random error, which arises from estimation inaccuracy and is related to the sample size [38]. To reduce these biases, a search was conducted in a broader, open database (Google Scholar) using the keywords "research skills," "scientific method," and "higher education". We found 3350 results, of which the first 20, ordered by relevance, were reviewed, using the same inclusion and exclusion criteria to validate whether the articles supported the results of the present study. Although some of them supported the link between knowledge of the scientific method and research skills, they did not consist of empirical studies focused on developing that relationship but had different themes. However, some were added in the introduction and others in the discussion to support the conclusions obtained. It was decided, therefore, not to expand the number of references in the review since they were considered representative of the scholarship of the subject in cured databases.

In addition, the review intended to analyze those articles that explicitly consider the scientific method in the education of higher-education learners, through which they develop research skills. It would seem trivial, but many of the investigations carried out in educational research need to establish a scientific method as a working guide. Understanding research methodology, enforcing strict criteria, and having scientific rigor leads to solid research that receives peer recognition. Therefore, this review is relevant to establishing a point of reflection on the role of a scientific method in educational research.

3. Findings

3.1. Country, Source, Content Area, and Educational Context

Table 3 shows that seven works were developed in the U.S.A., three in Australia, two in Indonesia, two in South Africa, and the rest in Mexico, the Netherlands, Russia, Turkey, and Canada. The journal or conference source with the most results (three) was CBE-Life Sciences Education. As we can see from the discipline or content area, most of the 19 papers were from science, technology, engineering, and mathematics (STEM) subjects and STEM education (students and teachers of areas such as chemistry, biology, electronics, bioengineering, informatics, and civil engineering), only one was from sociology, and two involved gender studies.

Table 3. Articles included in the systematic review.

ID	Country	Journal or Conference	Discipline or Content Area	Educational Context	Ref.
M1	USA	*Journal of Chemical Education*	Physical and Environmental Sciences Chemistry, Physics, and Engineering Natural Science, Chemistry Educational Studies	The regional summer research program of roughly 35 students per year	[39]
M2	Mexico	*Electronics*	Engineering and Sciences Chemical Sciences Robotics and Advanced Manufacturing Industrial Engineering	Innovation week for bachelor's students in mechatronics engineering (6–9th semester) and bachelor's students in digital systems and robotics (7th semester)	[22]
M3	Indonesia	*Journal of Physics: Conference Series*	Geoscience, Physics Earth Science Studies Mathematics and Natural Sciences	Fieldwork relevant to geoscience themes	[40]
M4	USA	*The International Journal of Learning in Higher Education*	STEM vs. non-STEM Gender studies	STEM vs. non-STEM	[41]

Table 3. *Cont.*

ID	Country	Journal or Conference	Discipline or Content Area	Educational Context	Ref.
M5	The Netherlands	*Teaching Sociology*	Sociology	Replication course: social science research, with its hands-on application of quantitative skills to substantive questions	[42]
M6	Russia	*Education Research International*	Information Systems Mathematics and Legal Informatics	Online course in the basic scientific research	[43]
M7	South Africa	*South African Journal of Education*	Education	Faculty education programs	[44]
M8	South Africa	*African Journal of Research in Mathematics, Science and Technology Education*	Teacher Education Education	Six lecturers of biology, chemistry, and physics subjects	[45]
M9	USA	IEEE Frontiers in Education Conference	Engineering and Sciences STEM	Saturday, one-credit hour, research preparatory seminar course	[46]
M10	USA	*Journal of performance of constructed facilities*	Civil and Coastal Engineering	Forensic engineering course for civil engineers	[47]
M11	Australia	*Higher Education Research & Development*	Learning Development Human Biology, Educational studies	Lectures on human biology for undergraduate students	[48]
M12	USA	*American Society for Engineering Education*	Bioengineering, Bioprocess Scale-Up Engineering	An undergraduate introductory-level bioengineering course	[49]
M13	USA	*CBE-Life Sciences Education*	Biology, Science Education Life Science	Undergraduate biology majors	[50]
M14	Canada	*CBE-Life Sciences Education*	Biology, Science Education	Students enrolled in first-year biology classes	[51]
M15	Australia	*Advances in Physiology Education*	Physiology, Computer Based-Simulation Biomedicine, Science Teaching	Students in the second year of their three-year degree program	[52]
M16	Australia	*Studies in Higher Education*	Gender Studies, Empowerment Educational Studies	Interviews one year after degree completion	[53]
M17	USA	*CBE—Life Sciences Education*	Bioscience, Graduate Education Cell Biology, STEM	First-year doctoral students enrolled in the principles of molecular biology	[54]
M18	Turkey	*Participatory Educational Research*	Social Studies, Educational Research Science Education	Social studies faculty	[12]
M19	Indonesia	*International Journal of Instruction*	Automotive Engineering Vocational Studies Science Teaching, Technology	Students of the automotive engineering education program	[55]

Two studies considered the perception of faculty regarding the scientific method and how it can be useful for students to develop and practice research skills when it is explicitly part of a class assignment. One study explored the differences in the learning of research skills of students who participated in research activities and those who did not. In this work, the authors suggest that this may be associated with the knowledge of the scientific method.

At least four of the documents discussed short courses such as summer courses, field visits, Saturdays, or one-week events in which students were taught about their area while working under the scientific method's guidelines. In four studies, the scientific method was introduced after the third year within a four-year program, which may reflect that it might be better understood by a more mature student than a young one.

3.2. Methodology and Assessment Tools

This section assesses the methodological approaches utilized in the 19 studies. Nine studies were found to use a qualitative approach, six utilized a mixed-method approach, and only three used a quantitative approach (Table 4). As was observed, there are many instruments to measure if a student has developed a research skill. Studies employed multiple tools. Surveys, field notes, rubrics, scales, reports, activities (such as publishing scientific papers), tests, questionnaires, focus groups, quizzes, interviews, and oral presentations are data-collection instruments that the authors employed to measure the development of research skills. All these instruments could help measure whether the knowledge of the scientific method encourages the development of a given research skill.

Table 4. Methodology and data collection instruments reported in studies.

ID	Method (Qualitative, Quantitative, o Mixed)	Data Collection Instrument
M1	Mixed method	Student Assessment of Learning Gains toolset with Likert survey; questions derived from the Undergraduate Research Student Self-Assessment questionnaire.
M2	Mixed method	Field notes (individual and group) during the execution of the experiment and an anonymous, individual, 13-item survey.
M3	Quantitative-descriptive	All the data were assessed using individual rubrics distributed over and filled by the students.
M4	Quantitative	Research Self-Efficacy Scale; Academic Self-Concept.
M5	Qualitative	Weekly progress reports and written (anonymous) evaluations.
M6	Mixed method	A survey, internal testing of the system and tasks (exercises), peer review when publishing scientific papers, participating in research contests, winning scholarships according to scientific work, taking part in grant competitions at various levels, and test questions for lectures.
M7	Mixed method	Questionnaire (14 items).
M8	Mixed method	Questionnaire and individual interviews.
M9	Qualitative	A focus group.
M10	Mixed method	Graded assignments and mid-term and final examinations.
M11	Qualitative	A research-skill development framework.
M12	Qualitative	Rubrics, knowledge pre- and post-survey, team-based progress reports, quizzes, and oral presentations.
M13	Qualitative	A rubric for experimental design.
M14	Qualitative	A survey (14 items).
M15	Qualitative	A survey (4 items) and usage analytics.
M16	Qualitative	Interviews.
M17	Qualitative	Pre- and post-course surveys (14 items).
M18	Qualitative	Interviews.
M19	Quantitative	Scientific approaching learning instruments (employability skills reinforcement).

3.3. Research Skills and Students Impacted

Table 5 shows the related research skills mentioned in the articles and the number of students or impacted faculty. A variety of research skills were considered by the authors of the reviewed documents, ranging from observation and communication to problem-solving and data analysis, including statistics and the use of information technology.

Table 5. Developed skills and number of impacted students.

ID	Skills	Students
M1	Scientific communication.	560
M2	Problem-solving, intellectual curiosity (creativity, innovation, and motivation).	16
M3	Research (scientific problem solving) skills: explaining knowledge required; providing good information; assessing critical information; synthesizing-analyzing and applying new knowledge; and communicating good knowledge.	32
M4	Research (critical thinking, problem-solving).	191
M5	Quantitative research skills (statistical and critical thinking).	20
M6	Choosing a topic of scientific research, scientific search, analysis, data processing, and finding effective solutions using information technology.	242
M7	Science process skills.	75
M8	Interpreting data, questioning, observing, the ability to construct an argument, measuring, the ability to design an experiment, problem-solving and critical thinking, recording and communicating information.	6
M9	Research skills.	5
M10	Research skills and applying scientific method (first principles skills, technical writing, critical reading, and a knowledge of the civil engineering business).	16
M11	Knowledge production is based on a framework for research skill development.	120
M12	Problem-solving, critical thinking, technology literacy, creativity, independent learning, excellent communication, and collaboration skills.	72
M13	Design of experiments.	300
M14	Critical-thinking ability and conceptual understanding.	420
M15	Experimental design, data analysis, and understanding of the core physiological concepts associated with the practical class.	421
M16	Embark and clarify, find and generate, evaluate and reflect, organize and manage, analyze and synthesize, and communicate and apply.	130
M17	Self-efficacy and research skills.	103
M18	Observation, communication, cooperation, and problem-solving.	391
M19	Effective relationship skills (leadership and flexibility), workplace skills (time management and the use of technologies), and applied knowledge skills (critical thinking and problem-solving).	450

As observed, eleven studies impacted more than 100 students (103–560), which gives reliability to the information collected for this review. In six documents, between 10 and 100 people were impacted, while only two impacted less than ten people. The original manuscripts can be consulted for further details of the proposed frameworks in the documents.

3.4. What Is the Association between the Scientific Method and the Development of Research Skills by Higher Education Learners?

Among the 19 selected documents, conflicting ideas were found regarding the significance of the knowledge of the scientific method in developing and practicing research skills. From an opposing point of view, it was mentioned that no single scientific method is useful for skill development. Aguilar et al. [46] stated that teaching the steps of a scientific method takes time away from fundamental research. However, more authors attribute the benefit of presenting the scientific method to higher-education learners to develop research and other skills. For example:

3.4.1. Critical Thinking and Problem Solving

- Montgomery et al. [39] developed a teaching–learning process using the segmented scientific method so that students could master each step separately. Students developed critical thinking by providing precise and complete answers to research questions. This protocol has been used for 18 consecutive years.
- Jeffrey et al. [51] surveyed the attitudes of first-year biology students toward components of the nature of science. It was found that elements such as the scientific method improved the attitude toward science and, even more, towards an expert knowledge of science. In addition, the study mentions that it is through scientific research that skills such as critical thinking and problem-solving are obtained, which are required to interpret the results of an experiment.
- Baker and DeDonno [41] mentioned that critical thinking skills may be associated with the knowledge and understanding of the scientific method. Self-efficacy in STEM students compared to non-STEM students was caused by the obligated teaching of the scientific method.
- In their work, Felix-Herran et al. [22] also used the scientific method for students to innovate solutions to solve challenges. The students had to understand the steps of the scientific method to solve problems in programming crewless aerial vehicles from a practical approach. The students perceived that the scientific method guided immersive activities to solve a challenge.

3.4.2. Other Skills

- Prevatt [47] found that teaching research, including the scientific method steps, can lead students to develop critical thinking, oral and written communication, statistical analysis, and other research skills.
- Knowing the scientific method influenced the increment in employability skills of teacher candidates, according to Hadromi et al. [55], since it helped candidates associate the learning material with real contexts. Creativity, but mainly workplace and relationship skills, were also increased.
- Bayram [12] wrote that, in social sciences curricula, the approach is to equip students with observation, communication, cooperation, problem-solving, and research skills while teaching the concept of scientific research, which is carried out through the scientific research method.
- Villanueva et al. [49] showed that in cross-disciplinary skills, such as bioengineering, students can develop engineering problem-solving, critical thinking, and collaboration) as well as scientific skills (e.g., creating and carryout out a scientific investigation) by encouraging the use and knowledge of the scientific method,.
- Quiroga and Choate [52] suggested that more realistic experiences of the scientific method occur when using online virtual experiments in which the student takes their own pace. In addition to developing research skills (experimental design, data analysis, statistics, and report writing), exposing students to experimental techniques and methodologies and facilitating the development of employability skills, such as communication, quantitative reasoning, problem-solving, and teamwork, can help to reduce the noise of the laboratory environment.

The scientific method favors the development of scientific process skills. Still, in countries such as South Africa, conceptual understanding is more valued and prioritized [44]. Authors from this country have focused on education for pre-service teachers and the importance of teaching them science process skills to transfer knowledge to their future students. They formulate a skills framework based on the arguments of previous authors to state that the scientific method is not a discrete process [45]. Willison and O'Regan [56] mentioned that the basic research methods have remained almost unchanged since 2008. They support Molefe by noting that prioritizing knowledge and context are essential in developing research skills and those skills' frameworks.

Other authors explain that the scientific method steps can also be used to verify and extend previously published works [42]; that is, to carry out replicative studies. Bazhenov [43] mentioned that the scientific method enters the instructional function of universities for the application of knowledge and that it is an effective method for scientific research in various careers, which, in turn, generates research skills and abilities to develop in organizations. In their study, Dasgupta et al. [50] mentioned some students' deficiencies in the treatment of variables and the constructing of a hypothesis, essential parts of the scientific method. They designed a rubric for diagnosing students' experimental design knowledge and difficulties; these skills could be developed after the student's exposure to the scientific method.

Finally, although the studies do not mention the scientific method, they do mention research skills, concluding that they are necessary for the satisfaction of employers or postgraduate studies. For Hariyono et al. [40], specific research skills developed through fieldwork minimize the gap between learning that is focused on data collection and analysis, quantitative analysis, scientific literature use, and the knowledge and skills to use learning outcomes in the field. Lachance et al. [54] mentioned that both men and women have no difference in their self-efficacy in research skills at the doctorate stage, and Ain et al. [53] assured that both men and women have no difference in employer perception. However, each emphasized a facet of the full range of research skills: "Women in the study emphasized ensuring an appropriate direction for investigation, including through communication as a process; and men a deep analysis to make sense of data. Together, women and men may make a formidable investigative force".

3.5. Under What Context (Theoretical or Laboratory Courses) Is Applying the Scientific Method Helpful in Developing Research Skills?

Previously, a "cooking recipe" with detailed steps of the experiments was required in laboratories. Nowadays, it is more important that students can plan experimental protocols and solve problems, and implementing the scientific method is a way of doing so. This is in practical laboratory courses [39], in which presentations and written documents help build research and communication skills.

In other cases, the laboratories have migrated to practical classes in which methods, such as challenge-based learning (CBL), have used the scientific method to generate skills. In the CBL challenges, differentiated modules of theory and practice are implemented. The students comment that the designed activities allow them to learn new concepts and apply the theory, qualifying the learning experiences with high scores (i.e., 9.38/10) [22].

Research skills (such as formulating hypotheses, identifying evidence, combining different evidence, and arguing reasoning) were also developed through fieldwork and through direct interaction with the environment [40]. This way, the gap between theoretical knowledge and the development of field-specific skills is minimized. It is also emphasized that theoretical courses must be completed before fieldwork [40]

Another study discriminates between the laboratories taken at the beginning and the end of a career. Initially, courses are based on research, while at the end, they are based on experience. To develop research skills such as critical thinking, interaction with experienced researchers with knowledge of the scientific method [12] is recommended because students could play an active role and not only follow a "cooking recipe".

Commonly, STEM students are exposed to the scientific method in some areas of their curriculum [41]. However, the authors suggested the strategy be implemented in non-STEM areas as well, since the generated skills can be transferred to professional and life decision-making [41]. Some students used to choose non-STEM careers, inferring they would be less complicated. Therefore, they tended to feel less confident in research activities due to the myth surrounding the association between research and the STEM field. Supporting the proposal by the authors in one of the review documents, students from sociology were asked in a theoretical class to replicate a published study on an area following the scientific method [42]. Examples like this could be used in other non-STEM courses to develop research skills.

Another work organized a systematic structure of introductory scientific research courses including theoretical and practical aspects. While in the theoretical sessions students learned about critical parts of the scientific method, databases, and scientific publication processes, the students applied the acquired knowledge in the practical sessions. In this sense, self-education has been highlighted as a critical aspect [43].

Molefe and collaborators argued that the skills to be developed in designing laboratory activities should be kept in mind [44]. Some teachers spend more time teaching conceptual content than developing skills through hands-on activities, the most-used excuse being that the available time is not enough, highlighting the gap between theory and reality. A constructivist approach will allow the development of scientific skills [12]. In addition, two requisites for obtaining this result are resources and independence from instructors and an improvement in students' attitudes towards practical work [45].

Interestingly, some students prefer practical and creative activities outside the classroom, as it allows them to better understand the concept of research involving time and collaboration. In the study by Aguilar et al. [46], students expressed that the content of laboratory activities, in this regard, were more applicable to their interests than previous activities. The importance of the basic teaching of the scientific method is recognized, and interactive, hands-on experiences complement the learning and define it more as "science".

Through the creation and design of a framework of skills to be developed with the support of the scientific method, it is possible to design theoretical and/or practical classes in which students obtain higher averages and build research skills [56]. This also increases the confidence of students to become competent in STEM areas [49]. Evaluation rubrics are of vital importance for this purpose [50].

Research-based laboratories that consider the scientific method are another resource that researchers use to encourage the development of research skills in higher-education learners. Their designs are planned in terms of student interest and confidence. These laboratories should be based on inquiry that encompasses the nature of knowledge and the scientific method as elements in improving students' attitudes toward science [51]. The systematic writing and reading of students' theoretical classes that generate inadequate technical skills have been corrected with practical resources or even guest speakers [47].

Virtual experimentation is another resource reported. Students better understand practical concepts and experimental processes than in theoretical classes [52]. In the described case, virtual and self-paced experiments contributed to the development of research skills (experimental design, self-efficacy, analysis, synthesis, entrepreneurship, articulation, and communication capacity), using the available time efficiently and learning the scientific method more realistically compared to classes of theory or conferences [53–55].

4. Discussion

The knowledge of the scientific method is directly related to developing research skills. However, the term "scientific" has been erroneously associated with skills only developed in a laboratory or with STEM subjects. However, an opening in this rigid concept has begun to potentiate over the last decades. The application of the scientific method depends on the context. As a structured system, its practice helps students develop valuable skills in everyday life and, more importantly, as a condition of employability for STEM and non-STEM research areas.

As is shown in Table 4, research skills and competencies have been evaluated through concepts' learning gains and rubrics. To measure the development of research competencies and learning with the scientific method, the following is a non-exhaustive list of requisite actions that may be of use to the reader, as were reported in the 19 studies in this review:

- Instructors providing field notes when students solve challenges in fieldwork;
- The publication of scientific articles by students;
- Rubrics provided for the design of experiments;
- Written reports and exams;
- Self-perception or self-assessment surveys;

- Reported standardized instruments;
- Surveys before and after a course;
- The use of interviews or focus groups.

This list shows that research skills are hardly evaluated through exams. However, in most cases, this evaluation is left to the subjectivity of the instructor and the student. That is why the assessment must become a consensual process between the student and instructor. Faculty should also be instructed in the scientific method to evaluate accordingly to the students.

Another reflection from this work is that, in effect, the scientific method should be emphasized more in areas that are not STEM due to the benefits that this involves. According to the review documents, knowing and studying the scientific method benefits the student during their career and provides skills such as critical thinking, problem-solving, and oral and written communication. In general, the research skills that were found from teaching the steps of the scientific method are, but are not limited to:

- Self-efficacy;
- Critical thinking;
- Intellectual curiosity;
- Scientific communication;
- Data processing;
- Problem resolution;
- Use of information technologies.

From this list, the most-mentioned skills were critical thinking and problem-solving. In a recent study carried out by the authors of the corresponding article (data not shown), it was found that STEM students self-perceive themselves as having a high level of these two skills. This does not mean that other careers do not generate students with these skills. However, subjects that emphasize using the scientific method in non-STEM careers would be worth considering. For example, virtual experiments may be one resource that can be tested in non-STEM careers.

Practical work is necessary to correctly develop most research skills when the scientific method is taught. Some skills, such as oral and written communication, including those related to statistical analysis through replication studies, can be acquired in theoretical classes (referring us to theoretical courses as those in which there are no laboratories). However, the students do not come to associate the theory with its application through theoretical classes in which the method is explained. To do this, the resources used by the researchers include:

- Fieldwork (FW);
- Virtual experiments;
- Inquiry-based learning (IBL);
- Problem-based learning (PBL);
- Challenge-based learning (CBL).

Studies have found that artistic activities improve students' oral and written communication skills in STEM careers [57]. Conversely, an area of opportunity obtained from this review is to study if the realization of virtual experiments (STEM) can improve the research skills of non-STEM students, and then to compare these studies. On the other hand, the use of the scientific method in FW, CBL, IBL, and PBL in education can help improve the results of these teaching–learning strategies through a structure of the steps to follow in the research or in the resolution of problems and challenges, which can be replicated.

In studying the association between knowledge of the scientific method and the development of research skills in higher-education learners, we believe that the most important outcome of this work is that teaching the steps of the scientific method can be a simple and direct way to ensure the development of research skills in higher-education learners. Figure 2 conceptualizes this as a systematized way of performing research in higher education to validate the assessment of research skills in any context, whether it is in STEM courses, non-STEM courses, theoretical classes, or research labs. This allows us to generate contextual, research-skill development frameworks as academic evidence for educational standardization institutions [58].

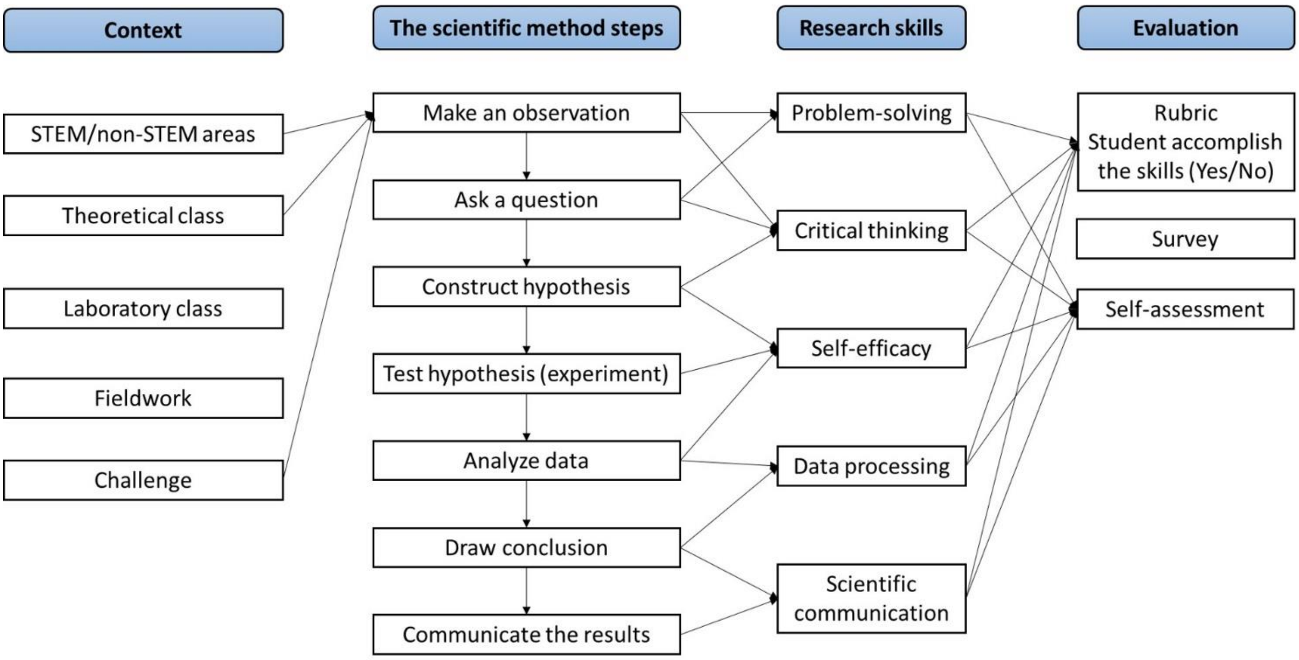

Figure 2. Conceptualization of the relationship between the teaching of the scientific method and the development and evaluation of research skills in higher-education students. The steps of the scientific method were based on the work of [59].

This concept can be modified according to the subject's needs or the activity to be developed, whether it is a replicative study or a laboratory experiment. Examples of these adaptations can be found in [60–62].

Other authors have also defined research competencies as a "set of specific skills for research, according to the logic of the scientific method" [63] based on "proven scientific reasons," and this has been set as necessary in citizen science, which emphasizes the development of research skills by higher-education learners so that their actions are more meaningful and sustainable [61]. These are likewise used for the solution of social problems [64], even at earlier stages. For example, [65] mentions that adapting primary scientific articles can be a preliminary step in teaching the scientific method to secondary school students. Workshops on how to use the scientific method have also helped develop research skills [66].

The scientific method is systematic, planned, and precise; faculty training is essential for the scientific method to contribute to addressing "pedagogical difficulties in general and teaching-learning problems in particular" [67]. This is particularly necessary for developing countries, where an increase in scientific production indicators is required [68]. In the study by [69], it was found that in the "recontextualization of science in society," the teaching of the scientific method promotes the desire of students to do research, even when it is not economically rewarding.

Limitations and Future Studies

The risk of bias presented in this document was addressed. The few studies found with such a broad searching equation are striking. Of the 55 articles selected, only 19 were included in the review, considering that the documents were open-access and that they were empirical articles and not reviews. This number may not be a representative sample, and we should have considered other databases. However, this study contributed to documenting that applying the scientific method in teaching higher-education students is invaluable in developing and practicing research skills. In future work, it would be essential to address and compare what methodologies are employed—not just the scientific method—to implement strategies through which students can develop the research skills that will serve them throughout life, even outside academia.

Another limiting aspect of the study, which can be attributed to the small number of articles found, is that no consensus was found on developing skills in each academic context. Although some authors reported that students of STEM careers developed more research skills than students of non-STEM careers, a variety of research skills were found that can be developed both at the entrance of the career and at the end. Opportunity areas comprehend gender studies and appropriate skills to be evaluated in hybrid-format classes (face-to-face and virtual).

Regarding the data extraction adopted in this document, this could be improved by implementing other types of data analysis; for example, using an integrative review [32] that considers not only empirical articles but also different types of sources such as literature reviews, books, and book chapters.

One of the outcomes of this review was a list of instruments for measuring research skills in particular contexts. According to the results obtained, a door is opened for our future studies, which will focus on evaluating the scientific skills of undergraduate students, comparing the development of scientific skills in students of face-to-face classes and students in virtual classes, and comparing the development of scientific skills of students who perform experiments in the laboratory and students who participate in theoretical courses, all framed in the steps of the scientific method, both in STEM classes and in non-STEM courses.

5. Conclusions

Some studies in the literature explicitly debate the application of the scientific method in developing research skills in higher education learners. In the articles reported in this literature review, we observed that applying the steps of the scientific method, whether in a week of research, fieldwork, or a semester class, ensures the development of research skills, which can be measured through rubrics. Studies indicate that their practice improves the development of these skills and increases the employability of graduates.

It may be that the scientific method, due its estimation as a “cooking recipe” during the last century, does not have as much fidelity on the part of faculty in STEM areas. However, structuring research is one of the best tools to enhance the development of research skills in science. In addition, the mere mention of a scientific method, according to the results of this review, can improve the development of life skills in students of non-STEM careers.

Context-dependent research skill frameworks have been reported, i.e., the type of subject in which the scientific method is taught, ranging from generic wisdom to scientific process skills. To practice these skills, it is recommended that problem-based learning strategies or well-structured challenges are put into practice, considering the students’ maturity. Virtual experiments are a resource that can be used even in extreme cases, such as the COVID-19 lockdown, and are an excellent tool for practicing research skills.

We hope this document will be helpful for researchers in the educational area when it comes to encouraging and measuring the development of competencies in higher-education learners. The findings of this review lead us to conduct studies to determine and compare whether effectively teaching students the scientific method improves their understanding and development of research skills in STEM and non-STEM areas.

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