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Analysis of Pedagogical Content Knowledge in Science Teacher Education: A Systematic Review 2011-2021

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Abstract: Pedagogical content knowledge (PCK) consists of a set of understandings, knowledge, skills, and dispositions necessary for effective performance in specific teaching and learning situations. Using Scopus, EBSCO, and Web of Science databases, the study examines the progress of the PCK in science teacher education between 2011 and 2021. In total, 59 articles were reviewed, and 13 were selected according to the inclusion criteria. Among the findings, it stands out that the articles emphasize a series of tools used when teaching applied sciences, such as the use of educational technologies beyond the textbook or the integration of students' thinking. The articles state that PCK transcends subject knowledge and leads to subject knowledge for teaching. Finally, the literature has tried to answer how science teachers use PCK in the classroom, demonstrating strategies and practical value, both of which are vital for the functioning and application of their educational work.

Keywords: *Pedagogical content knowledge (PCK), science, teacher education, teaching.*

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Introduction

Teaching as a profession implies a field of knowledge that can be systematized and, therefore, communicated to others (Guerriero, 2017; Korthagen, 2017). However, a widespread common sense idea is that to be a teacher, it is enough to know some content. On the contrary, evidence indicates that knowing how to teach entails the power to transform disciplinary knowledge into teachable knowledge (Hume et al., 2019). In practice, this is not all that characterizes a good teacher (Benekos, 2016; Haider & Jalal, 2018; Merellano-Navarro et al., 2016; Morrison & Evans, 2018;) since, if it were so, all teachers, researchers, and experts would be efficient teachers.

For teachers to deploy their knowledge to their full capacity and according to their classroom context, mastery of pedagogical knowledge is required. This knowledge base consists of a set of understandings, skills, and dispositions that are necessary for effective performance in specific teaching and learning situations (Abell, 2008; Berry et al., 2016; Deng, 2018). This does not imply only knowing their specialty; rather, it involves various aspects of pedagogy. These ideas were developed by Shulman (1986, 1987) through his studies and research on pedagogical content knowledge (PCK).

The PCK is a theoretical framework that allows the understanding of teachers' pedagogical skills relevant to their teaching practice, thus becoming a model for research on the development of teachers' knowledge. The author described a program which sought to explain the basic components of teaching and how they were developed in teaching activities (Chan & Hume, 2019; Kim et al., 2018; Kleickmann et al., 2013; Neumann et al., 2019). In this line, authors such as Aydin et al. (2015) and König and Kramer (2016) point out that teachers with differentiated and comprehensive knowledge have better skills when it comes to planning, developing, and evaluating their lessons compared to teachers with limited and fragmented knowledge.

In the field of science teaching, a dominant position among PCK researchers has been the proposal of Magnusson et al. (1999) and Park and Chen (2012) who consider both there to be five components: a) Guidelines for teaching science; b)

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knowledge and concepts related to the science curriculum; c) knowledge and beliefs about science content among students; d) knowledge of scientific assessment processes; and e) knowledge of how science is taught from a didactic perspective. Consequently, PCK is considered to be a fundamental axis in teacher education, especially in science teacher education.

On the other hand, the knowledge acquired by the trainee science teacher in disciplines such as physics, biology and chemistry and between subjects of the same disciplinary area, for example, energy transformation or genetics in biology, leads to the integration of disciplinary and pedagogical knowledge. Consequently, teachers must know and understand the content they teach, including knowledge of the central facts, concepts, theories, and procedures of a given discipline field (Abell, 2008; Berry et al., 2016; Shulman, 2015) to make the specific science content understandable to their students.

In line with the above, research on the science teachers' knowledge at different professional moments, specifically initial training, trainees, novices, and experienced teachers, is mainly aimed at providing input for the reformulation of the science teacher education curricula as presented by the studies of Carlson et al. (2019); Chai (2019); Depaepe et al. (2013); Hudson et al. (2015); Kleickmann et al. (2015); and Schneider and Plasman (2011). The above is in a good understanding that if the professional practice of good teachers can be accessed and documented, it could be configured as an initial instance for novice teachers in order to assist them in their professional development. It can also provide important elements to incorporate into the initial training of science teachers (Winberg et al., 2019).

Some of the difficulties that arise concerning the students' knowledge of science are concepts that are too abstract or poorly related to the student's daily life; difficulties in problem-solving; and differences between the students' spontaneous knowledge and scientific knowledge, which results in alternative ideas about scientific concepts being presented by the students (Fong & Slotta, 2018; Irmita & Atun, 2018). However, research has shown that although science teachers have some knowledge of their learners' difficulties, they often lack the relevant knowledge to help the learners overcome their difficulties (Retnawati et al., 2017). Knowledge of the requirements for learning specific science concepts should include the specific knowledge, skills, and abilities needed for learning, as well as knowledge about how to help students acquire and develop this knowledge and skills (Barnhart & van Es, 2015; Carrillo-Yañez et al., 2018; Demirdöğen et al., 2016).

In this context, the PCK construct can serve as a lens to assess the science content development and teaching strategies of prospective science teachers. Accordingly, the present systematic review aims to contribute to the debate on the question of how pre-service teachers teach science and how PCK is applied in classrooms. Accordingly, the aim of the study is to analyze the progress of PCK in science teacher education between 2011 and 2021.

Methodology

The study consists of a literature review. A second-level analysis is conducted based on the review of primary sources to address the research question and purpose of the study (Newman & Gough, 2020; Zawacki-Richter et al., 2020). The use of systematic reviews as a research method facilitates the development of new knowledge on a particular topic, thereby promoting the development of new theoretical foundations in the field of study (Xiao & Watson, 2019). The research was developed between January and March 2022 to analyze the development of PCK in science teacher education using advanced search in Web of Science, Scopus, and EBSCO databases.

Using the recommendations of Naufal et al. (2021), the objective, methodological rigor indicators, search sources, and inclusion and exclusion criteria of the study were determined. The following keywords were used to configure the search equation: "PCK", "STEM teachers" and "teaching". The Boolean operator "AND" separated each of the concepts used. The search equation was then entered into the Scopus, EBSCO, and Web of Science databases, applying different filters to refine the results (see Table 1).

Table 1. Elements of the Search Strategy and Selection Process

Inclusion Criteria
1. Articles; qualitative, quantitative, and mixed approaches.
2. Reports from the last 10 years, 2011-2021.
3. Published in English, Spanish, French, and Portuguese languages.
Exclusion Criteria
1. Duplicate studies.
2. Presentations, dissertations, or conference proceedings.
3. Articles that address the use of technology, values, interculturalism, and higher education.
4. Articles that address preschool education.

59 articles that met the predefined inclusion criteria were included. When the exclusion criteria were applied, 10 duplicate articles were eliminated. In the first phase, the articles were selected by reviewing the title and abstract, and in

the second phase, the full text was analyzed. With this procedure, 36 articles were eliminated, selecting a final sample of 13 documents considered for the present review, which met the inclusion criteria of the research (see Figure 1).

Through a process of inductive thematic analysis, the content of the studies was reviewed. This type of analysis is defined as a method that allows identifying and identifying and organizing the nodes (themes) and sub-nodes (sub-themes) that emerge as relevant and that subsequently become the object of analysis, being a fundamentally descriptive method that seeks to identify the most relevant themes that emerge from the descriptive data (Vaismoradi et al., 2013).

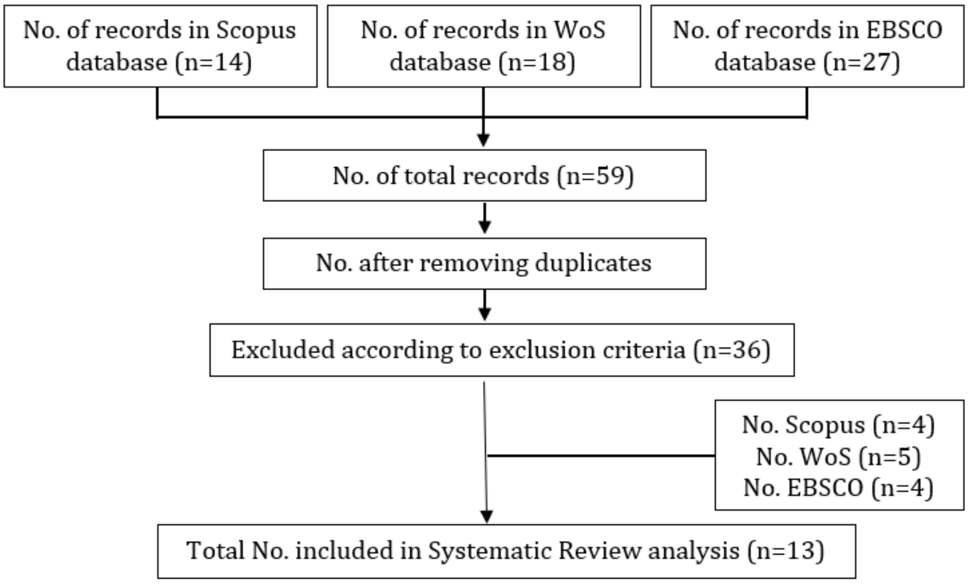

Figure 1. Diagram of the Process of Information Flow through the Different Phases of the Systematic Review.

Results

The results obtained from the analysis of the 13 documents considered in this review are presented below. The trend shows that the study of PCK in science teacher education is mainly concentrated between 2016 and 2021, but especially, during the last two years. Regarding the study method used in these papers, qualitative research through case studies prevails. However, findings from a quantitative and mixed perspective are also reported. A synthesis of the articles is shown in Table 2, indicating the name of the author(s), the study method used, a brief description of the objectives, and the main conclusions.

Table 2. Results Found in the Bibliographic Review.

No	Author(s)	Research Method	Study Description	Study Findings
1	Norville and Park (2021)	a) Qualitative b) Case study	It explored the impact of cooperating teachers on the PCK of science teacher trainees.	The findings of this research imply that PSTs should have more autonomy during student teaching with a strong focus on thinking.
2	Suters et al. (2021)	a) Mixed method b) Convergent parallel design b) Survey, narrative	This study analyzes the STEM Literacy in the Classroom to Enable Societal Change project, which supports the professionalization of STEM teachers.	The results showed a statistically significant increase in content knowledge, technological pedagogical knowledge of content, transfer of the use of 3D printing, inverted teaching methods, and screencast design in the classroom.
3	Zhai et al. (2021)	a) Qualitative b) Video analysis	The construct- irrelevant variance (CIV) was used in this research. The PCK of the science teachers was applied based on a video.	This research provides further support for the idea that investigators should make an explicit identification of COI and potential sources of CIV and use measurement models to examine COI.
4	Aydin-Gunbatar et al. (2020)	a) Mixed method b) Interviews c) Content representation a) Survey	This paper examined the PCK of STEM teachers using a continuing education course.	The findings from the study indicate that the study participants had no prior training on the essential characteristics of integrated STEM. After training, some of the participants were able to balance across STEM disciplines, which was coded as a PCK.

Table 2. Continued

No	Author(s)	Research Method	Study Description	Study Findings
5	Faikhamta et al. (2020)	a) Mixed method b) Pre- and post-survey, observations, teachers´ reflective journals.	This article studies the implementation of a professional development project in STEM based on PCK. It analyzes teachers' conceptions of STEM education and its application.	The results indicate ’hat the program positively affected the teachers' attitude toward STEM education in terms of their knowledge and application.
6	Sarkim (2020)	a) Qualitative b) Design research	The aim of this investigation is to provide a model of teacher professional training with the development of the PCK as the main evaluation indicator for improvement.	The results provide a model for a teaching professional development program that centers on the teachers' knowledge to support their activities in the classroom.
7	Vossen et al. (2020)	a) Qualitative b) Multi- case study	The purpose is to contribute insights to the teachers' personal and shared knowledge about how research and design can be connected.	The outcomes of this research indicate that a professional learning community, in which teachers with diverse backgrounds construct knowledge and instructional strategies together, can be a powerful method for improving personal PCK and collective knowledge.
8	Zhai et al. (2020)	a) Quantitative b) Survey	In this study, we evaluated the scores of machines and science teachers with respect to the potential construct-irrelevant variance (CIV).	The findings suggest that the settings influence the teachers' performance but the impact depends on the construct of interest.
9	Dong et al. (2019)	a) Quantitative b) Survey	This study constructed a hypothesized model that included teaching self-efficacy, administration support, discipline knowledge, and colleague support. This was followed by investigating its structural effects on the STEM teachers' engagement.	The results indicate that teacher self-efficacy, pedagogical design, and collegial support are substantial predictors of teacher involvement in STEM teaching.
10	Goodnough et al. (2019)	a) Qualitative b) Case study	In this study, a large-scale professional learning program focused on assisting the teachers in improving their practice and confidence when teaching science using inquiry-based learning was developed.	Changes in teacher orientation, teaching strategies, the knowledge of assessment, student learning, and science curriculum were reported. Teacher effectiveness and student learning are connected and contribute to PCK growth and changes in the classroom practice.
11	Park et al. (2018)	a) Quantitative b) Survey	This study investigates which measures of teacher quality in science teaching predict particular PCK levels.	The statistical results suggest that biology education and teaching at the high school level were the most meaningful predictors of the PCK total scores.
12	Suh and Park (2017)	a) Qualitative b) Multi-case study	This paper investigated commonalities in science teachers' PCK.	The results indicate that argumentation-based teacher guidance, particularly in terms of how students learn, is crucial to their continued application.
13	Allen et al. (2016)	a) Qualitative b) Case study	This study conceptualizes the process of adaptive teaching in STEM.	The results demonstrate that teachers who possess a well-developed STEM PCK and the ability to draw on their vision while reflecting through a constructivist approach to STEM teaching and learning are well positioned to engage in the adaptive teaching process.

Following the guidelines of Kiger and Varpio (2020), the categories for data analysis were established. The results provided by the thematic analysis allowed the generation of the following categories: 1) PCK and Pedagogical Strategies in the Classroom, and 2) PCK, Initial and In-service Teacher Training. Table 3 identifies the categories along with the authors addressing each category.

Table 3. Categories and Authors

Categories	Authors
PCK and Pedagogical Strategies in the Classroom	Allen et al. (2016); Suh and Park (2017); Suters et al. (2021); Zhai et al. (2020); Zhai et al. (2021);
PCK, Initial, and In-service Teacher Training	Aydin-Gunbatar et al. (2020); Dong et al. (2019); Faikhamta et al. (2020); Goodnough et al. (2019); Norville and Park (2021); Park et al. (2018); Sarkim (2020); Vossen et al. (2020);

Discussion

PCK and Pedagogical Strategies in the Classroom

In this first category, the articles suggest a broader perspective of what science is and means in the classroom, and then apply it to students through pedagogical strategies. The studies point out that practicing and learning science allows students to acquire a different way of thinking about and explaining the natural world. In other words, learning science is socializing the practices of the scientific community, including its specific goals, the way it views the world, its problems, and its way of sustaining knowledge claims (Faikhamta et al., 2020; Sarkim, 2020; Vossen et al., 2020; Zhai et al., 2020). At the social level, the process involves an introduction to the concepts, symbols, and conventions of the scientific community, which is not something that students discover on their own.

The literature reports that there are different reasons why students may present difficulties in learning scientific concepts, and the teacher should be aware of each type of difficulty and its approach (Azevedo, 2018; Fletcher et al., 2018). Some of the difficulties that arise in relation to science knowledge are concepts that are too abstract or poorly related to the student's daily life, difficulties in problem-solving, and differences between the student's spontaneous knowledge and scientific knowledge, resulting in alternative ideas about scientific concepts presented by students (Hanuscin et al., 2011).

Science learning in school involves a conscious articulation of what constitutes theories, connecting the teaching process with theoretical issues and their teaching practice (Nilsson & Karlsson, 2019). Consequently, the PCK perspective of science learning appears to be a process that is not only limited to teachers' knowledge and understanding of science teaching, but also, to student characteristics and successful practices, which adds practical value to PCK (Goodnough et al., 2019; Park et al., 2018; Suh & Park, 2017; Suters et al., 2021). Science teachers frame their perspectives on teaching and learning within a constructivist paradigm and position themselves as the facilitators of learning, engaging in self-reflection and encouraging reflection among their students (Allen et al., 2016; Suh & Park, 2017; Suters et al., 2021).

Consistent with the above, once this conceptualization of what science is obtained, the studies consequently invite a description of the teaching strategies. The study by Allen et al. (2016) reports that PCK may not be evident, especially when it is limited to a lesson or the teacher's teaching practice. Commonly, teachers design activities and plan teaching strategies that present implicit goals in their practice but rarely think about the reasons that led them in that direction. Thinking about a science teacher model reinforces the need for teachers to look for didactic strategies within which the students solve problems and assimilate knowledge, for example, active learning activities as well as information and communication technologies (Benegas & Villegas, 2022).

Finally, the analyzed articles emphasize, to a great extent, a series of tools that are commonly used when teaching applied science such as the use of educational technologies beyond the textbook, such as computer labs, video rooms, Internet access, data shows, science labs, media, digital whiteboards, netbooks, TV, DVDs, and videos, among others. Making use of diverse materials is important for the teacher to qualify regarding their mastery of the content and student learning, thus exercising an application of PCK (Zhai et al., 2020, 2021) and reinforcing their confidence and ability to foster learning environments that can attract students to science (Goodnough et al., 2019).

In this sense, in these educational settings, classes should be part of a series of activities that include a process of planning, teaching, reflection, and conducting action research in the classroom in a conscious process in pursuit of better engagement in teaching (Dong et al., 2019; Faikhamta et al., 2020). As part of the professional development of science teachers, the literature suggests that the disciplinary component be incorporated through pedagogical strategies developed in the classroom, providing teachers with opportunities to work collaboratively, to share their teaching strategies, thus enhancing their professional knowledge, and consequently the didactic construction of the collective professional knowledge, which ultimately preserves new practices. (Suh & Park, 2017; Suters et al., 2021; Vossen et al., 2020).

PCK, Initial Training, and In-service Teachers

The categories of PCK and pre-service and in-service teachers show that in practice, teachers articulate diverse knowledge using their professional, disciplinary, curricular, experiential, and practical training that is constructed throughout their lives and professional trajectory (Norville & Park, 2021; Park et al., 2018; Sarkim, 2020; Vossen et al., 2020). This is because, to a large extent, what teachers know about teaching comes from their experience as learners. From this, they construct and reconstruct their classroom practices, thus highlighting that science teachers possess a better understanding of the nature of the discipline (Faikhamta et al., 2020). This occurs through a recursive exercise of continuity and rupturing with the theories and theoretical perspectives from which their own PCK makes sense.

Authors such as Magnusson et al. (1999) claim that the study of science teachers' PCK reveals that a precarious knowledge of content and pedagogy correlates with ineffective use of teaching strategies. In fact, they suggest that the development of PCK requires knowledge of three categories of knowledge: content knowledge, pedagogical knowledge, and understanding of context. The literature reports that science teacher education courses should consider providing a space for undergraduate students to reflect on specific content so then key pieces of the content to be taught are subject to didactic and pedagogical analysis and discussion (Dong et al., 2019; Faikhamta et al., 2020; Goodnough et al., 2019).

Consequently, the articles analyzed in this review point out and make a great emphasis of what research is, relating that studies on the knowledge of science teachers at different professional moments (initial training, apprentices, novice, and experienced teachers) have as their main objective the provision of inputs for the reformulation of the science teacher education curricula. The above is under the principle that, if the professional practice of good teachers can be accessed and documented, it can serve as a starting point for novice teachers and thus help them in their training and adaptation (Allen et al., 2016; Aydin-Gunbatar et al., 2020; Norville & Park, 2021; Vossen et al., 2020). On the other hand, there are different ways of conceptualizing PCK. The authors propose that this theoretical basis helps to improve the teachers' competencies (Sarkim, 2020). It is important to know and present which model is being used so then the results can contribute to the development of the theoretical models already proposed (Park et al., 2018).

Consequently, it is not enough to reflect on the relationships between knowing and doing as it is also necessary to think of the science teacher as a figure challenged to use scientific knowledge, educational technologies, and innovative and creative didactic strategies that, many times, were not present in their initial training. However, they are demanded in the school classroom in terms of the need for challenging and relevant strategies for students that improve their confidence when teaching science.

Conclusion

PCK transcends subject knowledge and leads to subject knowledge for teaching. In the case of the teaching profession, its need is more than evident in the application of science. This has been reflected in the studies selected in the systematic review presented. In this same sense, the present article delves into aspects related to the use of PCK in the classroom as a transversal and fundamental element in the comprehensive training of future teachers and practicing science teachers.

The literature review has tried to answer how science teachers use PCK in the classroom, demonstrating different strategies which are vital for the functioning and application of their educational work. Teaching practices have shown that there is a strong influence manifested in the type of tools used in the classroom; videos, the Internet, science laboratories, and digital whiteboards among others to fully meet the objective of the class and to perform their work with greater security and mastery of the subject of science. This implies the adaptation of the teacher to the cultural and social reality of the student's immediate environment, generating a classroom climate that facilitates and invites learning.

On the other hand, PCK is constructed, especially in the stages of elaboration, application, and evaluation, using the teaching activities undertaken by the science teacher. PCK also distinguishes an excellent teacher from someone who only knows the content, the difference being that the teacher possesses an arsenal of forms of representation derived from knowledge of the practice. This makes it possible to transform the content into a range of forms of understanding that are accessible by the students. On the other hand, the study of a teacher's PCK is quite complex due, among other aspects, to the fact that it is implicit knowledge that must be made explicit in some way.

It can be concluded that the use of PCK as a pedagogical strategy for science teachers constitutes a relevant and necessary field of research. At the level of future teacher training, this study leads to a rethink of the initial training that they are receiving at university and the degree of adequacy of the same regarding the knowledge and mastery of PCK. For this, there should be more studies and research that relate PCK to the science teachers working in the classroom.

Recommendations

This research opens several inquiries, for example, how teachers' PCK develops in their professional practice, as well as how to deepen the understanding of the development of PCK in science teachers from the perspective of active teaching, learners, and practicing teachers. Additionally, future research could consider the proposals of the Refined Consensus Model of PCK, analyzing factors such as teaching experience, teachers' content knowledge (PCK), and how to determine science learning that promotes the development of PCK.

Limitations

It is recommended to consider other languages and to expand the search into other databases that contain specialized journals in the field of science education. Alternatively, longitudinal studies that examine the teaching of science teachers may be appropriate.

Conflict of Interest

The authors declare no potential conflicts of interest.

Authorship Contribution Statement

Almonacid-Fierro: Concept and design, data acquisition, data analysis/interpretation, drafting the manuscript, critical revision of manuscript, analysis, supervision, and final approval. Sepúlveda-Vallejos: Concept and design, data acquisition, data analysis/interpretation, drafting the manuscript, critical revision of the manuscript, analysis, supervision, and final approval. Valdebenito: Drafting manuscript, critical revision of the manuscript, final approval. Montoya: Drafting manuscript, critical revision of the manuscript, final approval. Aguilar-Valdés: Drafting manuscript, critical revision of the manuscript, final approval.

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