A Systematic Review of Pedagogical Content Knowledge for Teaching Nature of Science

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Abstract: This paper addresses the critical nexus between Pedagogical Content Knowledge for Nature of Science (PCK-NOS) and effective science teaching. Employing a systematic review following PRISMA guidelines, the study explores key characteristics and elements of PCK-NOS across selected articles (1990-2021). The analysis reveals three themes on PCK-NOS publications and four overarching themes on PCK-NOS framework elements. Discussions highlight the inadequacies of teachers' PCK-NOS, emphasizing the challenges in delivering NOS-infused science lessons. Contrary to prior assumptions, the paper challenges the simplistic link between teachers' NOS conceptions and PCK-NOS proficiency. The study underscores the pivotal role of subject matter knowledge, pedagogical knowledge, and the integration of assessment and pedagogical practices in fostering effective PCK-NOS. In conclusion, the study advocates for explicit exposure and training for teachers to enhance their competence in teaching content knowledge, especially in the context of NOS-integrated instruction. The identified knowledge bases provide valuable insights for future interventions and teacher training programs, emphasizing the multifaceted nature of PCK-NOS and its crucial significance in advancing science education.

Keywords: Pedagogical Content Knowledge, Nature of Science, Systematic Review

1. Introduction

In an era marked by unprecedented technological advancements and widespread knowledge dissemination, scientific literacy is no longer a privilege but a societal imperative. Recognizing this shift, the Organisation for Economic Co-operation and Development (OECD) has underscored the critical importance of individuals mastering the competency to "Research, evaluate, and use scientific information for decision making and action" in its PISA 2025 science framework (OECD, 2023). The increasing concern over the acceptance of ostensibly 'scientific' beliefs without substantive empirical support, despite credible evidence to the contrary, heightens the need for individuals to cultivate a skeptical mindset. A scientifically literate person must question potential conflicts of interest, assess the existence of a scientific consensus, and consider the expertise of information sources (OECD, 2023). Consequently, epistemic knowledge about science has become more pivotal than ever.

Recognizing the urgency of fostering a robust understanding of the Nature of Science (NOS), numerous countries are reshaping their educational landscapes to prioritize scientific literacy as a fundamental curriculum goal and an integral component of education reforms (Vinodhen, 2020; Yildirim et al., 2020; Jain & Luaran, 2020). These reforms emphasize the need for students to develop an informed perspective on the epistemology of science, understanding the intricacies of how knowledge is acquired and validated. While there is an increasing amount of literature showcasing the beneficial effects of directly instructing students on the Nature of Science (NOS) (McComas et al., 2020), there remains a notable lack of comprehension regarding the correlation between teachers' perspectives on NOS and the implementation of these perspectives in their teaching methods (Lederman, 2007). This gap underscores the importance of exploring a critical epistemology labeled as "Pedagogical Content Knowledge of NOS" (referred to as PCK-NOS in this paper), a dimension essential for science teachers. PCK-NOS plays a pivotal role in ensuring that educators can stimulate deeper thinking when students engage with science knowledge and skills. As we navigate the landscape of science education, it becomes imperative to delve into this crucial aspect of teacher preparation and instructional effectiveness for a comprehensive understanding of how NOS is incorporated into science teaching practices.

Moreover, it is essential to smoothly incorporate and instruct NOS principles throughout various science-related subjects within educational environments for students to acquire a comprehensive grasp of the Nature of Science (NOS). To accomplish this objective, educators need not only a comprehensive understanding of NOS but also specialized knowledge in PCK-NOS. Despite research indicating that possessing sound NOS understanding does not necessarily translate into effective communication of these concepts to students (Demirdogen et al., 2015) many other studies inversely claimed that other factors such as subject matter expertise (Supprakob et al., 2016) and teacher's beliefs (Grossman, 1990) are involved in the cultivation of PCK-NOS skills among teachers.

While NOS elements are incorporated into curricula and standards delineate the specific NOS tenets to be covered at each educational level, teachers often lack the necessary education and training to meaningfully teach and assess these tenets. This deficiency poses challenges in evaluating whether learning outcomes related to NOS are achieved and whether students may be harboring misconceptions about NOS. This review centers on exploring teachers' PCK-NOS, as documented in research literature.

By scrutinizing the current state-of-the-art in this field, we aim to gain insights into the key facets of PCK-NOS which will further inform a framework for teachers' PCK-NOS, derived from a systematic review of the existing literature.

2. Teaching Nature of Science as part of science education reform

The National Science Teachers Association (NSTA) (n.d.) in America states that "The eventual goal of science education is to produce individuals capable of understanding and evaluating information that is, or purports to be, scientific in nature and of making decisions that incorporate that information appropriately, and, furthermore, to produce a sufficient number and diversity of skilled and motivated future scientists, engineers, and other science-based professionals". There have been debates about what should be the actual aim of science education. A huge concern is placed on nurturing science literate students, both globally (McComas et al., 2020) or locally (Jain & Luaran, 2020).

Scientifically literate individuals are individuals who can understand science and apply it into their daily life (Demirbas et al., 2012). Höttecke and Allchin (2020) states that sound understanding of NOS is vital to scientific literacy and having a literate public. The National Science Teaching Association (NSTA) in America asserted that NOS education is pivotal in preparing students to be scientific literate individuals as NOS deepens students' understanding about science concepts, develops their ability to make well-informed decisions in their daily life and appreciate science as a part of human culture (NSTA, n.d.). NOS, or Nature of Science, encompasses the recognition of science as a means of acquiring knowledge, along with the underlying values and beliefs integral to the formation of scientific understanding, or simply, the "what and how" of Science (Clough and Olson, 2007).

Moreover, the idea of including NOS in science lessons has been advocated for many years (Halai, 2010). It was found by McComas et al. (n.d.) that when purposefully planned, NOS instruction could be effective. "Effective NOS instruction does not happen by chance" (Clough, 2012). Teachers should have an accurate understanding of NOS and internalise the importance of NOS by recognising it as a pivotal goal in science education. However, studies have shown that teachers have a lack of knowledge on NOS. Akerson et al. (2011) has attributed this to the inadequate and inefficient NOS instruction resulting in teachers being unable to teach NOS effectively in their science classrooms.

Askindehin (1988) as cited in McComas et al. (2020) states that NOS should be purposefully and overtly taught. It is important for teachers to express NOS as a part of their lesson objective(s) and NOS instruction should be planned in the context of everyday life so that students can see the relationship between what they learn and how it could be applied (Clough, 2012). Teachers should address NOS in a range of activities such as "laboratory activities, videos, reading assignments, interactive science content presentations and have discussions (Question and Answer session)" (Clough, 2012). Clough also suggests that teachers should make students think during science lessons especially about NOS, how science and scientists' work.

Research also suggests that informed NOS understandings can be developed by engaging students in inquiry (Abd-El-Khalick, 2012, Beh, 2011). Inquiry sets a suitable context for the development of informed NOS views for both teachers and students. However, Abd-El-Khalick (2012) suggests that an opportunity to reflect about the inquiry experience should be given as it is the core for an individual to achieve NOS understanding (explicit-reflective approach). Didactic and implicit teaching is ineffective to help students develop sound concepts about different aspects of NOS (Lederman & Lederman, 2019). In a study conducted by Khishfe and Abd-El-Khalick (2002) with two groups of students who had naive NOS views (prior to intervention). It was found that a larger number of students in the group who went through the explicit-reflective approach in learning NOS were able to develop more informed views as compared to the group who went through the implicit inquiry-oriented approach. This shows that the explicit-reflective approach is much more effective as compared to the implicit inquiry-oriented approach.

The complexity of NOS increases when science is closely tied and influenced by social and cultural factors which increases the complexity of NOS. Ma (2012) states that there will be a difference in terms of how western science is understood when it is taught in other countries due to the influence of culture.

2.1 Pedagogical Content Knowledge of teachers and science teachers

The well-grounded notion of Pedagogical Content Knowledge (PCK) was first introduced by Shulman (1987) to illustrate the complexity of a teaching profession. It also focuses on enhancing students' understanding on how certain topics, problems and issues are arranged, constituted and re-framed to meet different interests and ability levels of students (Kathirveloo & Puteh, 2014). Shulman (1987) also states that PCK is unique to teachers, depending on how teachers integrate their pedagogical knowledge (what they know about teaching) with subject matter knowledge (what they know about what they teach). PCK can be viewed as a continuum as teachers obtain more knowledge of PCK when they progress (Pompea & Walker, 2017). It is believed that teachers already have some form of PCK through their learning experiences as students (van Driel et al., 1998), and their level of PCK increases through teacher training courses, formal practice as teachers as well as further professional development training courses.

Teachers have been identified as one of the most influential factors in student learning (Lumpe, 2007). Hence, it is important for teachers to develop PCK so that deeper understanding of students in relation to the subject matter can be enhanced. In the context of science education, there was an attempt by Veal & Makinster (1999) who developed PCK taxonomies, with the aim to illustrate that PCK is a dynamic and developmental process. Hence, they proposed a hierarchical structure, with the foundational knowledge base being the content knowledge, followed by knowledge of learners, which then topped by 8 inter-related attributes of PCK, namely context, environment, assessment, pedagogy, curriculum, socioculturalism, classroom management and nature of science (Veal & Makinster, 1999). However, in a later pentagonal PCK model of science teachers, nature of science was regarded as part of the sub-components that shape teacher's orientation towards science teaching, alongside their beliefs about purpose of science learning, and beliefs about decision making (Park & Chen, 2017). Teachers' beliefs about nature of science in this pentagon model of PCK, however, is limited to the use of argument-inquiry and social interactions among science practitioners during those inquiries. Past research has not treated PCK-NOS with much detail. Hence the following research questions guided our synthesis of findings across the articles reviewed: (1) what characterizes the publications related to PCK for NOS in terms of their (a) aim and (b) research approaches, and (2) what are the explicit and implicit elements of PCK for NOS framework reported in the publications?

3. Methodology

The process in selection of articles for analyses is based in PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Statement (Moher et al., 2009).

a) **Identification**: The databases engaged in this study are from Web of Science, Google Scholar, Scopus-indexed journals and Education Resources Information Centre (ERIC). The search was carried out in the third quarter of 2022. The range of time of the search was from year 1990, the year where the inception of NOS was made to be formally taught in the international curricular and sparked the reform of science education worldwide (American Association for the Advancement of Science [AAAS], 1990). The Boolean search term used was "pedagogical content knowledge", "Nature of Science" AND "NOS-based teaching practices", "Nature of Science" OR "NOS-based teaching practices". Other search terms akin to NOS were also included to repeat the Boolean search. Among the terms used were "epistemology of science", "nature of scientific knowledge", "epistemic understanding of science", and "views on science". Other search terms akin to PCK used were "teaching", "teaching practices" and "pedagogical knowledge". This process resulted in 151 hits.
b) **Screening**: The screening eliminated 131 articles, as there were monograph presentations, non-peer reviewed articles, and editorials. Articles with 8 pages or less were discarded for validity issues (Mayring, 2000). Only articles which covered research done within PCK for NOS, and not PCK for scientific content or PCK per se were included to align with the objective of this systematic review.
c) **Eligibility**: Articles that referred to NOS and its alternative terms which were used in the title, abstract, and keywords were selected.
d) **Inclusion**: 17 journal articles from various peer-reviewed journals ranging from 1990 to 2021 in terms of publication timeline were included for analysis.

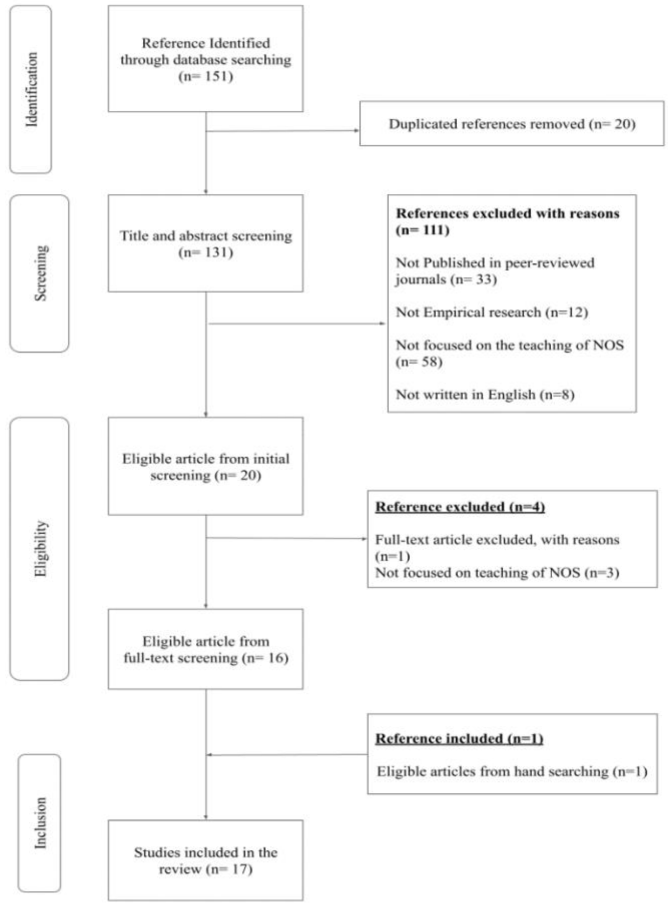

Fig. 1 Procedure of literature selection for systematic review

2. Data analysis

The articles were analyzed descriptively based on qualitative content analysis (Mayring, 2000). The whole procedure consisted of four stages as proposed by Saldana (2013).

First, the first author skimmed through the articles and extracted the information pertinent to the analysis, namely year of publication, author(s), country where the study was conducted, size of data involved, and the methodological design employed by the study. After that, both the authors read all the articles in detail and categorized the findings from each full text into preliminary themes aligned to the research objective. In the third step, more scrutiny was done on all the full text, in the effort to identify codes and categories for each theme. It is worthy to note that the step two and three were done by the authors independently to ensure reliability of the findings. At the end of the process, the authors then met again to consolidate their respective findings. Eventually, the themes related to the publication on PCK-NOS resulted in three themes, while there were four overarching themes related to the elements identified as part of PCK-NOS framework.

3. Findings

3.1 Descriptive Overview

The final studies selected for the review consisted of 17 journal articles from 1990 to 2023. The most publications related to PCK-NOS were from 2011 to 2020. In terms of the geographical locations as presented in Table 1 below, it was identified that most of the studies were predominantly done in the United States of America (n=7). The density of studies done in those regions are justified because the earliest proponents of nature of science as part of the science education reform agenda started in the United States, with the American Association for the Advancement of Science [AAAS] (1990).

The context of study on the other hand, was focused on pre-service teachers from various backgrounds and their year level of academic studies, as well as in-service teachers with varied years of experience. These two groups of participants across different studies analysed are relevant as all the studies were looking at the teaching of NOS using the PCK framework. Table 2 below details this information.

Table 1: Breakdown of countries where studies were conducted and its frequency

Countries	**Frequency**
United States of America	7
Palestine	1
Spain	1
Türkiye	2
Thailand	1
Taiwan	1
New Zealand	1
No mention	3

Table 2: Range of years for published articles and its frequency

Year published (Range)	Number of articles
1990-1995	1
1996-2000	2
2001-2005	2
2005-2010	2
2011-2015	4
2016-2020	5
2021-2022	1

RQ1: What characterizes the publications related to PCK for NOS in terms of their (a) aim; and (b) research approaches?

The first research objective was to find out the motivation driving all the studies documented by the journal articles and to look at the research approaches used by those studies.

Aim of studies of the journal articles

The analysis of the aims revealed three overarching themes across the reviewed literature.

A) Investigated existing PCK-NOS:

There were only two studies which aimed to study their participants' existing PCK-NOS. For instance, there was one investigation which specifically studied the PCK-NOS of teachers (Supprakob et al., 2016). The findings from the study indicated that the six novice chemistry teachers had insufficient Pedagogical Content Knowledge (PCK) related to instructing the nature of science (NOS) across all its components. While they demonstrated strong chemistry knowledge and held acceptable perspectives on certain aspects of NOS, these results suggest that the teachers did not effectively incorporate or teach as their attention was primarily directed towards teaching chemistry content. Echoing the similar aim in studying PCK-NOS, Bennetts (2021) explored the teacher's ability in a New Zealand school to transfer NOS policy into practice based on the science curriculum. Bennetts (2021) further studied, in the same article, how the school leadership can support this need (Bennetts, 2021). The study however, found that despite the prominence of NOS in the curriculum for over 10 years, teachers still faced various challenges in integrating the teaching of NOS in their science lessons.

B) Investigated the relationship between teachers' NOS conceptions with their classroom practices:

There were five studies under this theme which investigated the relationship between participants' NOS conceptions and their actual classroom practices. The research provided nuanced insights into PCK-NOS held by different participant groups, such as Biology teachers (Lederman, 1998), pre-service teachers (Mellado, 1997; Mesci et al., 2020; Bell et al., 2000), and beginning secondary science teachers (Schwartz & Lederman, 2002).

The findings of studies under this theme concluded that there was no relationship between teachers' NOS conceptions with their PCK-NOS (Lederman, 1998; Mellado, 1997). The studies also suggested a few mediating factors for teachers' enactment of PCK-NOS, such as subject-matter knowledge, NOS knowledge and NOS instruction intentions (Schwartz & Lederman, 2001). Additionally, another study under this theme also further listed teacher's prior experiences and pedagogical preferences as mediators for teachers' PCK-NOS (Bell et al., 2000).

C) Intervention to develop NOS and NOSPCK:

This prevalent theme underscores researchers' collective effort to enhance PCK-NOS within their target audience through interventions, which were documented by eight studies. These interventions varied in methods and duration, with the shortest intervention spanned over one week (30 hours) through an intensive professional development programme focusing on NOS teaching (Dogan et al, 2013). Similarly in Wahbeh and Abd-El-Khalick's (2014) study, the intervention was teacher's NOS-dedicated professional development course, which spanned six weeks. Other interventions included a 14-week course such as Philosophy of Science (Abd-El-Khalick, 2005). Studies in Research in Science Education (Demirdogan et al, 2015) and Inquiry and Natures of Science, Technology, and Engineering (INSTE) (Kruse et al., 2017) investigated how these courses affected the participants' PCK-NOS. Notably, there was one study in 2015 which explored the impact of Lesson Study in this context, spanned over 5 weeks. The longest intervention was 2-5 years, which measured the implications of a secondary science teacher education program on their perceptions on PCK-NOS. Table 3 detailed the interventions for each study.

Table 3: Details of intervention and studies

Author	Intervention
Wahbeh & Abd-El-Khalick (2014)	A six-weeks NOS-dedicated teacher professional development summer course (total contact hours: 36)
Abd-El-Khalick (2005)	A 14-week Philosophy of science course which were split into two courses-a 4-week and 10-week interventions
Dogan et al. (2013)	One-week (30 hours) long intensive professional development summer workshop on the teaching strategies of NOS
Demirdogan et al. (2015)	Two semester Research in Science Education course with a total of 10 activities in NOS instruction.
Akerson et al. (2015)	5-week period using the Lesson Study model.
Herman et al. (2012)	2 to 5 years course that extensively addressed the role of accurate and effective NOS instruction in science teaching.
Kruse et al. (2017)	Inquiry and Nature of Science, Technology and Engineering (INSTE) course

Research Approaches

In this systematic review, we examined a total of 17 studies, of which 15 adopted a qualitative research approach. These studies employed diverse strategies for data collection, including classroom observations and in-depth interviews aimed at comprehending the rationale behind participants' behaviors during observations, portfolio analyses, and analyses of lesson plans.

Two studies (Wahbeh & Abd-el-Khalick, 2014; Bell et al., 2000) employed a mixed-method design, utilising pretests, posttests, and delayed tests to measure the impacts of interventions on the participants. These two studies specifically explored conceptions related to Nature of Science (NOS) using established instruments, rather than the PCK-NOS per se. The qualitative section of the design, however, determines the participants' PCK-NOS by adopting interviews and lesson observations.

RQ2: What are the explicit and implicit elements of PCK for NOS framework reported in the publications?

Our systematic review identified four overarching elements derived from the analyzed literature, revealing variables that significantly influence teachers' NOSPCK.

Element 1: Teacher's conception of NOS and NOS with the subject matter

This element delves into how teachers' understanding of NOS shapes their pedagogical choices and instructional strategies in a science lesson. The need for sound NOS understanding, as justified by Demirdogen et al., 2015), allows the teacher to have "some comfort in their NOS understanding to teacher NOS". Similarly, this need was echoed by other studies which highlighted the impact of teachers' perceptions and beliefs about the Nature of Science (NOS) on their NOSPCK (Schwartz & Lederman, 2001; Lederman et al., 2011).

This interpretation, however, is inconsistent with several studies analysed, as they suggested from their studies that teachers' conceptions of science do not necessarily influence classroom practice

(Lederman, 1998; Mellado, 1997; Supprakob et al., 2016; Mesci et al, 2020; Bell et al., 2000). To further complicate this polarization of matter, Schwartz & Lederman (2001) asserted that the perceived relationship between NOS and science subject matter also plays a crucial role in affecting the participants' teaching of NOS.

Element 2: Teacher's Subject matter knowledge

The consistent and critical element influencing teacher's PCK-NOS reported in all literature is the teacher's subject matter knowledge. The depth and accuracy of a teacher's understanding of the scientific content positioned them better when it comes to providing context-relevant examples while explaining NOS ideas to their students. This was acknowledged and documented by studies such as Lederman (1998), Schwartz & Lederman (2001), Bell et al. (2000); Mesci et al. (2020) and Wahbeh & Abd-El-Khalick (2014).

Element 3: Teacher's pedagogical knowledge and preferences

Element 3 encompasses the preferred pedagogical approaches teachers employ to teach NOS, which were influenced by the years of their teaching experience. The longer the teacher is experienced in teaching, the more pedagogical approaches are advanced and varied compared to a novice teacher (Lederman, 1998). Experienced teachers, therefore, can select appropriate NOS- related resources and materials and are more comfortable enacting various strategies such as inquiry teaching (Wahbeh & Abd-El-Khalick, 2014; Abd-El-Khalick, 2005) on the other hand, reported and used the term "teachers' perception of teaching" in which he identified as one variable which mediated teacher's PCK-NOS. In this reporting of our systematic review, we included teacher's perception of teaching NOS (on whether it is relevant or not to be taught) under this element as literature has reported that teacher's perception of their pedagogical preferences during their teaching (Veal & Makinster, 1999).

It is worth noting that despite acknowledging that teachers have robust understanding of instructional strategies, studies like Hanuscin (2010) and Wahbeh & Abd-El-Khalick (2014) highlighted that it is not necessarily the case that they are well-armed with assessment of NOS understanding of their students.

Element 4: Teachers' perceptions of their students

The final element identified in the literature is teachers' perceptions of their students' NOS. This includes understanding how teachers view their students' abilities, prior knowledge, and receptiveness to NOS concepts, all of which play a role in shaping the teacher's approach to PCK-NOS. This was not a popular finding and from the articles we sampled, it was only reported in Lederman (1998).

4. Discussion of findings

While there were lesser attempts to study existing PCK-NOS of teachers and pre-service teachers (theme 1), majority of the studies were focused on identifying the relationship between NOS conceptions and PCK-NOS of teachers and subsequently suggested the mediating factors of teachers' enactment of PCK-NOS (theme 2) as well as improving teachers' PCK-NOS through various interventions (theme 3). The result of our systematic review revealed that teachers and pre-service teachers are inadequately equipped with PCK-NOS and hence not competent in teaching NOS-infused science lessons. In reaction to this, many studies are revealing that explicit-reflective teaching of NOS (Abd-El-Khalick, 2001) are necessary to aid teacher's understanding, to which we observed that the focus of many studies sampled were on devising interventions geared towards a favourable NOS understanding of teachers and teachers-to-be.

In line with this, all the studies which utilized qualitative and mixed-method approaches are appropriate, as in-depth findings are able to then inform the researchers better on how effective certain intervention has been, identify the variables involved in enacting PCK-NOS during teaching, or providing a more wholesome picture of participants' existing PCK-NOS understanding in studies, when compared to a quantitative approach aiming for generalisation.

Fundamentally, PCK, as established by the work of Shulman (1987), is contended to be based on a teacher's perceptions of teaching and the subject matter (Davis, 2004). While there is not much consensus in the body of literature on how exactly PCK is developed, two consistent elements mentioned (van Driel et al., 1998; Lederman et al., 1994; van Driel et al., 2002) and are aligned to the finding of this paper are teacher's knowledge on subject matter, and their teaching experience.

According to Schiering et al. (2023), teachers developed the fundamental PCK at the pre-service stage, for example, during their teacher preparatory programme, as the PCK-courses offered during the preparatory programme were found to be an important pre-cursor to their PCK development (Sorge et al., 2019). This implies that it is a challenge for teachers to have PCK without going through or being exposed explicitly on how to go about teaching content knowledge to their students. This is more complex in the teaching of NOS, because it must be integrated with another body of content, namely the science knowledge. As evident by the two studies analysed in this paper, the teaching of NOS is less prioritized when teachers need to ensure that students understand the content. It appears that an effective teacher of science needs to master science content knowledge, PCK related to science, NOS knowledge, as well as PCK-NOS.

The findings within Theme 2 challenge prevailing assumptions held by previous studies. It was common for prior research to assert a causal link between a teacher's proficiency in PCK-NOS and their foundational conceptions of Nature of Science (NOS). Numerous studies measured teachers' comprehension of NOS and posited statements such as, "Without a solid grasp of NOS, how can we expect teachers to effectively impart accurate NOS concepts to their students?" Consequently, these studies advocated for the inclusion of NOS courses in teacher preparatory programs, emphasizing the importance of educating teachers about NOS (Demierdogen et al., 2015; Schwartz & Lederman, 2001; Lederman et al., 2011). However, our current understanding suggests a more nuanced perspective. While it remains valid that teachers lacking a robust understanding of NOS may struggle to convey NOS concepts effectively to their students, the inverse is not necessarily true. Teachers also require support in developing PCK-NOS to seamlessly integrate NOS into their science instruction. The investigations identified within Theme 3 address this crucial aspect by examining diverse programs and interventions designed to enhance teachers' PCK-NOS.

In the subsequent phase of our analyses, we discerned consistent findings across diverse studies to identify the pivotal knowledge bases crucial for fostering PCK-NOS. Literature strongly supports the assertion that subject matter knowledge, specifically science content knowledge, emerges as the most frequently documented element in this context. Additionally, pedagogical knowledge assumes significance, influencing teachers' choices of pedagogical strategies and their capacity to identify suitable Nature of Science (NOS)-focused materials and resources for effective teaching and learning.

Furthermore, an essential perspective emphasized by Nader Wahbeh and Fouad Abd-El-Khalick (2014) in their study underscores the interconnectedness of assessment and pedagogical practices in the teaching of NOS. Their findings advocate against treating assessment as a distinct entity but rather advocate for its integration into pedagogical approaches to establish a cohesive instructional loop.

The study identified a noteworthy finding, highlighting that only one investigation has addressed the role of student perception in mediating PCK-NOS during teaching. Within the existing literature, Shulman (1986) and Veal and MaKinster (1999) have categorized this phenomenon under the umbrella of "knowledge of learners." They emphasized the broader scope of examining students' perceptions and their impact on teaching. Subsequent research, such as Barnett and Hodson (2001) has affirmed the significance of this factor in influencing instructional strategies. Nevertheless, a crucial gap in the current understanding remains, necessitating further evidence and studies to elucidate whether a similar dynamic is at play in the context of teaching NOS-integrated instruction. Additional research is imperative for a comprehensive grasp of the implications of student perception on the effective integration of Nature of Science into pedagogical practices.

5. Conclusion

In summary, our systematic literature review has illuminated critical dimensions within the landscape of PCK-NOS, shedding light on the challenges faced by teachers and pre-service teachers. The identified themes have delineated the predominant focus on the relationship between teachers' conceptions of NOS and their PCK-NOS, the mediating factors influencing teachers' enactment of PCK-NOS, and interventions aimed at enhancing teachers' PCK-NOS.

The development of PCK, as rooted in teachers' perceptions of teaching and subject matter, underscores the pivotal role of knowledge on subject matter and teaching experience. Challenges arise in the integration of NOS into pedagogical practices, especially given the intricate nature of aligning NOS knowledge with science content knowledge. The findings emphasise the necessity for teachers to undergo explicit exposure and training on effectively teaching content knowledge, particularly in the context of NOS-integrated instruction. Contrary to prior assumptions, our review challenges the one-dimensional link between teachers' foundational NOS conceptions and their proficiency in PCK-NOS. While acknowledging the importance of a solid NOS understanding, we argue that teachers also need dedicated support in developing PCK-NOS to seamlessly integrate NOS into science instruction. Additionally, the identification of subject matter knowledge, pedagogical knowledge, and the interconnectedness of assessment and pedagogical practices as crucial knowledge bases for fostering PCK-NOS informs future interventions and teacher training programs.

6. Co-Author contribution

The first author contributed to the conception of the study and wrote the problem statement, performed the data analysis, wrote the method and discussion. The second author organized the database, acted as the independent reviewer in deciding the inclusion and exclusion of papers and performed data analysis. The third wrote the introduction, prepared the table, figures, and references. All authors contributed to manuscript revision, read, and approved the submitted version.

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