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Systematic Review

Science Teachers' Pedagogical Scientific Language Knowledge—A Systematic Review

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Abstract: Since students' knowledge of scientific language can be one of the main difficulties when learning science, teachers must have adequate knowledge of scientific language as well as the teaching and learning of it. Currently, little is known about teachers' practices and, thus, teachers' knowledge of scientific language, in general, and the teaching and learning of it (Pedagogical Scientific Language Knowledge, PSLK) in particular. For this reason, with this systematic review, we seek to identify elements of pre- and in-service primary and secondary science teachers' PSLK. The search was conducted on the database Education Resources Information Center (ERIC) and resulted in 35 articles with empirical evidence after the selection process. The results have been deductively and inductively categorized following the framework of the Refined Consensus Model of Pedagogical Content Knowledge, elaborating elements of different knowledge categories that shape PSLK, as well as PSLK itself (e.g., knowledge of (i) scientific language role models, (ii) making scientific terms and language explicit, (iii) providing a discursive classroom, and (iv) providing multiple representations and resources). We can conclude that more research on PSLK is needed as analyzed articles are mainly based on case studies. Additionally, this paper shows a need for a stronger focus on scientific language in teacher education programs. Implications for further research and teacher education are discussed.

Keywords: pedagogical scientific language knowledge; scientific language; disciplinary literacy; systematic review; language of science

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1. Introduction

The overall goal of science education is to promote scientific literacy. Therefore, students must acquire competencies in explaining phenomena scientifically, evaluating and designing scientific inquiry, as well as interpreting data and evidence scientifically [1]. These competencies aim to enable students to engage with science-related issues as reflective citizens [1,2]. To reach this goal, first, students must have a certain level of competence in the language of instruction as it is the prerequisite for the acquisition of knowledge [3,4], and science does not only rely on practical work [5,6]. Additionally, students must acquire skills in scientific language as "almost all of what we customarily call 'knowledge' is language, which means that the key to understanding a subject is to understand its language" [7], as cited in [8] (p. 3). Every activity in the science classroom is essentially bound to at least one dimension of language [8–11], as there are reading, writing, listening, and speaking [9], and every activity must be completed by engaging in all these dimensions of language [12]. In conclusion, mastering scientific language is the key to understanding and participating in science classes, including chemistry [13,14].

As an example, in the chemistry classroom, *Chemish*—as the language of chemistry—is important in teaching and learning chemistry [15]. Mastering Chemish is a key-competence that students must develop according to the curriculum (e.g., [16–20]). However, learning Chemish is one of the major difficulties in learning chemistry [8,21]. The role of chemistry teachers in this process has been long known, as stated by Laszlo [22] (p. 1682): "Chemistry teachers are linguistic guides, they are interpreters. They teach their students how to craft well-formed chemical sentences". Thus, the primary responsibility for ensuring that students learn Chemish and therefore become scientifically literate lies with chemistry teachers. The same applies to science in general. If the difficulties when learning scientific language are not addressed by the teacher, this could lead to scientific language anxiety on the side of the students and hinder their learning of science [23]. As a consequence, science teachers must be adequately prepared to teach scientific language; address their students' difficulties while learning scientific language; and make scientific language and, therefore, scientific content, accessible to them. But what knowledge do science teachers need when it comes to teaching and learning scientific language?

2. Theoretical Background

Shulman [24,25] divides teacher knowledge into *Content Knowledge* (CK), *Pedagogical Knowledge* (PK), and *Pedagogical Content Knowledge* (PCK), the last of which is a "special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" [25] (p. 8). In the last years, research on teachers' PCK has proliferated and several different models for (science) teacher pedagogical content knowledge have been developed (an overview can be found in [26]). Taking these models and the experiences of many researchers on PCK in science education into account, Carlson and Daehler [27] present the Refined Consensus Model (RCM) based on the *Teacher Professional Knowledge and Skill model* (TPK&S, also known as the Consensus Model (CM)) by Gess-Newsome [28]. In the RCM, the foundation of science teachers' PCK is the following *professional knowledge bases*: the non-discipline-specific (i) *pedagogical knowledge*, (ii) *knowledge of students*, (iii) *assessment knowledge*, and (iv) *curricular knowledge*, as well as discipline-specific (v) *content knowledge*. Additionally, the *learning context* also influences teachers' PCK and serves as an amplifier and filter for teachers' actions as it constitutes space and time for science teaching. It includes, e.g., *learning environment* and *student attributes*.

PCK itself is divided into three distinct realms that can vary in their grain size (discipline-specific, topic-specific, or content-specific):

- *collective PCK* (cPCK), which is articulated and publicly shared specialized knowledge among professionals (teachers, researchers, and educators) for teaching particular topics in a particular context to particular students,
- *personal PCK* (pPCK), which is individual to every teacher for teaching in particular learning contexts for particular students on a particular topic and is influenced by contributions of others as well as the own learning and teaching experiences,
- and *enacted PCK* (ePCK), which is a subset of pPCK and can be seen as a reflection on and reflection in action. It is knowledge a teacher draws on to plan, teach, and reflect on a particular lesson with a particular topic and purpose to particular students in a particular way.

In general, teacher professional knowledge bases (i–v) and PCK influence one another, and they are shaped by peers, students, teachers' amplifiers and filters, and others.

As the named professional knowledge bases and PCK, which emerges from them, matter when teaching scientific language, the question arises which approaches of teacher knowledge with the focus on teaching and learning scientific language already exist. Many approaches can be found that focus on language learning of English Language Learners (ELLs). Within one of these approaches, Galguera [29] responds to Shulman's concept of PCK with a general need for teachers to develop *Pedagogical Language Knowledge* (PLK) as PCK for academic language development. Building on this notion of PLK, Bunch [30] distinguishes between (i) PCK of second language teachers, (ii) PCK of subject teachers that is tied to their subject area(s), and (iii) PLK of subject teachers that prepares them to work with

ELLs. He further states that based on a different conceptual foundation, PLK is to be seen as a distinct dimension of teacher knowledge. Thus, PLK "can be construed as knowledge of language *directly related to disciplinary teaching and learning and situated in the particular (and multiple) contexts in which teaching and learning take place*" [30] (p. 307) with a special focus on ELLs who face the double challenge of acquiring the foreign language whilst building knowledge through that foreign language. According to both scholars, teachers must develop (i) *language awareness* [31] as explicit knowledge about language, and using and perceiving language consciously, (ii) *critical language awareness* [32–34] which refers to social, political, and ideological aspects of language, and (iii) *metalinguistic awareness* "as conscious knowledge of the formal aspects of the target language (e.g., grammar)" [35] (p. 248). In the context of scientific language, metalinguistic awareness focuses on the "hidden conventions in science that govern the way language is used to produce and communicate scientific knowledge" [36] (p. 1312). This requires metalanguage, which "refers to the technical terms for talking *about* scientific language" [36] (p. 1312). To develop PLK and become a linguistically responsive teacher, opportunities to practice are crucial as the notion of language as action serves as an overarching principle [29,30].

Another more practical approach for linguistically responsive teacher education in the context of culturally and linguistically diverse students is proposed by Lucas and Villegas [37]. Following their framework, *linguistically responsive teachers* need to develop: "(a) multiple ways of learning about and building on their students' linguistic backgrounds; (b) current understandings of second language acquisition; (c) the ability to identify the specific language demands of a given classroom task; and (d) multiple ways of scaffolding content-specific language supports for multilingual learners" [38] (p. 558). Similar to this, the framework of *Disciplinary Linguistic Knowledge* (DLK) refers to "teachers' knowledge of academic discourse characteristics distinct to a particular discipline" [39] (p. 3) to teach content to ELLs. Possessing DLK enables teachers to act as a language role model to show ELLs how language is used in the discipline to communicate meaning. That means that DLK includes knowledge of the disciplinary language that enables teachers to identify the language demands inherent in the discipline and thus provide ELLs with tools to help them communicate in and through this disciplinary language. As well as Lucas and Villegas [37] ((c) and (d)), Turkan et al. [39] identify two components of DLK: "(a) identifying linguistic features of the disciplinary discourse and (b) modeling for ELLs how to communicate meaning in the discipline and engaging them in using the language of the discipline orally or in writing" (p. 9).

Building on these approaches, a question arises whether scientific language is to be seen as a foreign language, and thus the beforementioned approaches to teacher knowledge for teaching (academic) language can be transferred to the scientific language. In foreign language acquisition, the native language serves as a frame of reference or mediator [40]. In contrast, in scientific language acquisition—and thus also the acquisition of scientific concepts—the concepts and the reference system must be built simultaneously, thus a mediator could only be already acquired concepts [40]. Rincke [41] confirms this way of acquiring scientific language in physics: scientific language is not based on everyday language but has to be learned simultaneously with its frame of reference. Additionally, Hayden and Eades-Baird [42] argue that methods for vocabulary learning in English language arts cannot be applied crosswise to science. Therefore, it can be summarized that most of the approaches mentioned fail to recognize that scientific language can be a challenge for native speakers as well and, thus, knowledge of the scientific language and teaching and learning of it is required by all science teachers to be able to teach it successfully to *all learners*. So, there is a need for another approach when it comes to teacher knowledge of teaching and learning the scientific language.

Love [43,44] calls for the integration of *Language/Literacy Pedagogical Content Knowledge* (LPCK) in university teacher education as she considers subject teachers' poor knowledge of language and literacy demands of their subject area and their inability to address these overtly and deliberately while teaching, which was also confirmed by Mönch and

Markic [45]. However, a concrete concept of teacher knowledge of scientific language and teaching and learning of it is still missing.

To our knowledge, only the approach by Fulmer et al. [46] explicitly deals with teacher knowledge regarding scientific language. A focus lies here on *teachers' knowledge of language as an epistemic tool* in science classes. Teachers' knowledge of language as an epistemic tool is defined as "knowledge of the essential nature of language for learning science, including the roles of language for allowing students to create their knowledge (privately) and to test and validate their own and others' knowledge claims (publicly)" [46] (p. 461). They identify four interrelated but distinguishable sub-domains: (a) language is essential as science cannot be done without it, (b) language is constitutive as it is the base of thought, (c) language involves process and product as it is used and produces, and (d) language includes multimodal representations, as suggested by the Johnstone triangle [47].

Taking all these approaches into account, it should be noted that they call for (i) subject teachers' knowledge about language in general, but there is also a need for (ii) teacher knowledge about subject-specific language as a part of *disciplinary literacy* [48]. However, no approach has yet dealt in detail with teachers' knowledge of teaching and learning the scientific language. Hence, Markic [49] (p. 181) proposes that (future) chemistry teachers need to develop professional knowledge with the focus on Chemish: *Pedagogical Scientific Language Knowledge* (PSLK) as "teachers' Pedagogical Language Knowledge (PLK) with the focus on scientific language of chemistry", more precisely as "knowledge of scientific language related to teaching and learning chemistry, focusing on different scientific topics and contexts".

3. Research Question

Although linguistic demands of scientific language are extensively documented (e.g., [15,50–53]) and the importance of language in science education is increasingly recognized, Childs et al. [9], as well as Yore and Treagust [11], point out that little research has been done on the common practice of teaching scientific language in schools and thus on the pedagogical scientific language knowledge of science teachers. Hence, there is a need to document current practices and language usage in science classrooms to implement changes in science teacher education regarding how to interpret and use scientific language [52]. Additionally, some pre- and in-service teacher professional development initiatives that have recognized the role of scientific language in science education already exist (e.g., [37,54–61]). Nevertheless, less is known about the long-term effectiveness of these interventions and resulting pedagogical practices in science classrooms when it comes to teaching and learning scientific language and therefore PSLK. Since a detailed description about the structure of PSLK is missing, it is of interest to evaluate which of the teacher professional knowledge bases proposed in the RCM [27] are essential in teaching scientific language and therefore shape PSLK and what the concrete elements are that PSLK consists of. Therefore, the following research question guides this study:

What elements of pedagogical scientific language knowledge can be identified from current research findings following the Refined Consensus Model and which grain-size(s) (discipline-specific, topic-specific, or content-specific) do these elements have?

4. Materials and Methods

To answer the research question, a systematic review following the PRISMA 2020 statement [62] was conducted. Following this, the database ERIC (eric.ed.gov, accessed on 1 June 2021) was chosen for searching the literature, as it includes the most important journals on science education.

4.1. Selection of the Articles

4.1.1. Eligibility Criteria

- *publication year*: All articles published between 2002 and May 2021 were included in the review, since the final search was carried out on 1st of June 2021.

- *publication type*: Only journal articles that had undergone a peer-review process were included in the review. This excludes the use of books, book chapters, and journals that use other selection processes.
- *publication language*: As ERIC is a database only for English literature, literature of other languages is not considered.
- *study types*: Only studies with empirical evidence (quantitative, qualitative, and mixed methods) were included.
- *study participants*: Only articles with a focus on (future) science, chemistry, biology, or physics teachers in primary and secondary schools were included. Other sciences, e.g., astronomy, were excluded, as the main focus in primary and secondary education is on science in general and biology, chemistry, and physics as different subjects in secondary education.
- *search syntax*: As PSLK is a relatively new and unknown concept, starting from some keywords, further searches were made based on the results and keywords were adjusted. This process was repeated until the coverage and accuracy of the results were satisfying. The final search was carried out with the following search syntax: (abstract:("technical language*" OR "technical word*" OR "scientific word*" OR "scientific language*" OR "language* of science" OR "science language*" OR "chemical language*" OR "chemical word*" OR "language* of chemistry" OR "scientific vocabulary" OR "chemistry vocabulary" OR "chemical vocabulary") OR title:("technical language*" OR "technical word*" OR "scientific word*" OR "scientific language*" OR "language* of science" OR "science language*" OR "chemical language*" OR "chemical word*" OR "language* of chemistry" OR "scientific vocabulary" OR "chemistry vocabulary" OR "chemical vocabulary")) AND (abstract:teacher OR title:teacher) AND (abstract:(competencies OR knowledge OR beliefs OR awareness) OR title:(competencies OR knowledge OR beliefs OR awareness)) AND (science OR biology OR physics OR chemistry).

As we selected only articles in English, the results might be limited and produce bias. However, since major findings tend to be published in English to reach the international community, we decided to accept the bias produced by our choice. Another type of bias might be that some journals favor some publication types over others (e.g., quantitative studies may be favored over qualitative studies).

4.1.2. Exclusion Criteria

In the initial step, a sample of 127 articles is obtained. In the next step, the abstracts of each article are scanned, excluding those (64) which

- are theoretical or the study contained no empirical evidence (21)
- do not match the predefined study participants (35)
- do not contain any data about teachers' usage or knowledge of scientific language or (critical) language or metalinguistic awareness concerning scientific language (6)
- are not accessible (2)

For some articles, more than one exclusion-criterion applies. For those articles, the first exclusion-criterion along the list that applies to the article is chosen. In the case that the abstract does not reveal enough information (e.g., on the study type) the article is included in the second step—a full-text analysis.

After sorting out in the first step, 63 articles are left for further analysis. Out of these 63 articles, 28 articles are excluded during the second step, the full-text analysis, because they

- are theoretical or the study contained no empirical evidence (2)
- do not match the predefined study participants (6)
- do not contain any data about teachers' usage or knowledge of scientific language or (critical) language or metalinguistic awareness concerning scientific language (9)

- present intervention studies either (i) for in-service teachers with a focus on (scientific) language that contained no data of the status-quo before the intervention or involved no control group or (ii) for pre-service teachers that focused on the implementation of a specific teaching method (11)

A list of the remaining 35 articles which constitutes our sample can be found in the Appendix A, as well as the PRISMA flow-diagram (Appendix B, Figure A1).

4.2. Analysis

To analyze the articles in our sample, an analysis grid is developed. The following information is recorded in the analysis grid:

- the field of study (science, chemistry, biology, or physics),
- the study participants (pre- or in-service primary or secondary teachers),
- if the focus in the article was on teaching second language learners (SLLs) who have a native language other than the official language of the country or the language of instruction was different from the country's official language,
- what kind of study is conducted (qualitative, quantitative, and mixed methods),
- of what the data are comprised (e.g., questionnaire, interview, observation),
- a short sample description,
- the research question(s) or purpose of the study,
- what can be found about science teachers' knowledge and awareness of scientific language, and
- what can be found about science teachers' practices when it comes to teaching and learning the scientific language.

In the first step, all the information is extracted into the analysis grid that contributes to the research question. Keeping the RCM in mind, in the second step, the results of the studies are divided deductively into the following four main categories:

- Teacher Professional Knowledge Bases (Content Knowledge of Scientific Language, Curricular Knowledge, Pedagogical Knowledge, Assessment Knowledge, Knowledge of Students),
- Teacher Amplifiers and Filters,
- Learning Context, and
- PSLK

In the next step, as no further theories are known until this point about science teachers' PSLK, subcategories for the named four main categories are developed by using Grounded Theory [63]. Therefore, in the first step of open coding, the findings are summarized or paraphrased. Through axial coding, codes focusing on the same topic are then grouped and categories are constructed. Since the four main categories are already given, the last step of selective coding is only applied to some of the subcategories. The coding process results in the following category system (Table 1, bold: RCM categories):

Table 1. Categories influencing and constituting PSLK.

Teacher Professional Knowledge Bases	**Content Knowledge of Scientific Language**	
		Understanding of the Concept Behind Scientific Terms
		Semantic Relationships between Scientific Terms
		Characteristics of Scientific Language
		Content is Inextricably Bound to Language
		Metalanguage to Talk About Scientific Language

Table 1. *Cont.*

Teacher Professional Knowledge Bases	**Curricular Knowledge**	
		Knowledge of the Curriculum and (Alternative) Materials
		Vertical Curricular Knowledge
	Pedagogical Knowledge	
		Non-threatening and Appreciative Learning Environment
		Collaborative Group Work
	Assessment Knowledge	
	Knowledge of Students	
		Knowledge of Students' Prior Knowledge of and about Scientific Language
		Knowledge of Students' Difficulties with Scientific Language and its Use and Potential Roots of these Difficulties
		Knowledge of Differences in Students' Abilities Across Modes of Language
		Knowledge of Differences in Students' Language Ability Across Subject Areas
		Knowledge of Students' Learning Progress in Language Use
Teacher Amplifiers and Filters	Scientific Language Awareness	
		Grammar/Discourse Norms of Scientific Language
		Scientific Terms and their Morphology
		Semantic Relationships between Scientific Terms
		Teaching Scientific Language is a Task of Science Teachers
		Difference of the Scientific Language Register in Comparison to Other Language Registers
		Abstractness of the Concepts Behind the Terms
Learning Context	Student Attributes	
		Students' Prior Knowledge of and about Scientific Language
		Students' Difficulties with Scientific Language and its Use
		Students' Abilities Across Modes of Language
		Students' Learning Progress in Language Use
		Students' Experiences and Cultures
	Curriculum Materials	
Pedagogical Scientific Language Knowledge	Scientific Language Role Models	
	Development of the Concept Before Development of the Scientific Language	
	Making Scientific Terms and Language Explicit	
	Providing a Discursive Classroom	
		Providing Opportunities for Students to Practice Scientific Language
		Incorporating Multiple Dimensions of Language
		Negotiations of Term Meanings
		Asking Questions
	Providing Multiple Resources and Representations	
	Providing Scaffolds for Scientific Language Development	
		Oral Strategies
		Visual Aids
		Written Strategies
		Accepting That Students Use Less Scientific Terms
	Communicating Expectations Clearly	
	Specific Methods and Tools for Teaching and Learning Scientific Language	
		Glossary
		Graphic Organizer/Concept Map
		Scaffolding Written and Spoken Scientific Language
		Gamification
		Digital Resources

5. Results

First of all, it is noted that 15 articles of the selected sample explicitly focus on teaching second language learners (SLLs). Nevertheless, these studies are included as the focus of the article is not only on teaching language in general but scientific language and we assume that this knowledge is also helpful for teaching native students. It should also be noted that most of the studies are qualitative in their nature (only one solely quantitative) and most of the articles are published after 2015 (24), including 14 within the last three years.

The following section is organized following the developed categories (Table 1). According to the RCM, first, the details on *teacher professional knowledge bases* informing PSLK are presented. The scientific language awareness of science teachers serves as an *amplifier and filter* when putting the knowledge into practice and is also influenced by the *learning context*. *PSLK* itself appears to be comprised of several principles of teaching scientific language as well as some methods and tools which seem especially suitable for teaching scientific language. The grain-size of PSLK appears to be discipline-specific, as no explicitly topic-specific elements can be identified through the review.

5.1. Teacher Professional Knowledge Bases

5.1.1. Content Knowledge

- *Understanding of the Concept Behind Scientific Terms*: As proposed within models for teacher knowledge, content knowledge is essential for teaching the content. In the context of teaching and learning scientific terms, that means that teachers need to know (i) the concept behind different scientific terms [42,64,65], (ii) related synonyms [66], (iii) that the meaning of (scientific) terms is context-specific—especially concerning everyday language—[65,67–69], and (iv) symbolic representations [65]. Content knowledge also serves as a premise to be able to categorize s according to their importance within the discipline [42].
- *Semantic Relationships between Scientific Terms*: Another important part of science teachers' content knowledge regarding scientific terms is the knowledge of semantic relations between them [42,64,66,67,70,71]. Within these semantic relationships, it is important to know about commonalities and differences in scientific terms, to be aware of links between the terms to be able to express oneself correctly [42,67,70,71].
- *Characteristics of Scientific Language*: Several characteristics of scientific language were found to be known by science teachers. At the word level, prefixes [72], nominalization [73], and the use of specific terms [70,73,74] are thematized in the articles. At the sentence level, the syntactic structure is special to scientific language [70,73,74]. Concerning the text level, findings reveal knowledge about the passive voice [73], text types in general [73,75], and that spoken discourse consists of elements of text types and has its own discourse norms that differ from everyday language [68,74–76]. As a special characteristic of scientific language, other presentation forms are mentioned, e.g., diagrams, tables, symbols (word level), and formulae (sentence level) [65,73,74,77–79].
- *Content is Inextricably Bound to Language*: Another important point for teachers to realize is that content and language go hand in hand [46,74,80,81], as Fulmer et al. [46] phrase it, to see language as an epistemic tool through which knowledge is created and communicated.
- *Metalanguage to Talk About Scientific Language*: Within this systematic review, teachers are found to use metalanguage about the following topics: talking about prefixes [72], discussing the use of scientific terms [70,74,82], as well as comparing and contrasting key concepts, and therefore scientific terms [70], discussing the syntactic structure [70], and explicating scientific discourse norms [74].

What is found, however, is a tension between the knowledge teachers are expected to have on the side of the researchers and the knowledge they actually have. They are found to have a lack of knowledge of scientific terms [64–66], are unaware of their word choice [64,66], and are not able to explain scientific concepts [65,76] or express the semantic structure of a concept [71]. Furthermore, they lack knowledge about the characteristics of scientific language [73], especially the syntactic sentence structure, and different text types used in science [73,75,77].

5.1.2. Curricular Knowledge

As originally proposed by Shulman [24], curricular knowledge can be considered threefold: (i) to be knowledgeable about the curriculum material and alternative curriculum material, (ii) to have lateral curricular knowledge that refers to the curriculum of other subjects the students are studying at the same time, and (iii) to have an overview of the topics and contents vertically which means of the topics that have already been taught or will be taught within the subject. This can also be transferred to curricular knowledge regarding scientific language. Results reveal knowledge for two domains:

- *Knowledge of the Curriculum and (Alternative) Materials*: Curricular knowledge is especially needed to identify core scientific terms [42,80,83,84] and define language objectives as part of the lesson plans and tool for planning [74,85,86]. Furthermore, during lesson preparation, curriculum materials, e.g., textbooks, can be analyzed towards which and how (often) scientific terms are used [87,88].
- *Vertical Curricular Knowledge*: Identifying key scientific terms that appear a few times in the curriculum across multiple grade levels or only occur once and therefore are not particularly important for the students to know [42,84]. Additionally, vertical curricular knowledge is needed to identify new terms and what prior knowledge students might have about a scientific term and connect it to the actual learning [87,89].

One may categorize the scientific terms according to their importance when learning science: (i) high-frequency, well-known terms, (ii) terms students need to know for learning science during their school years as they are part of curricular content, and (iii) highly specialized scientific terms used in special contexts that are not necessarily needed to understand the content [84].

Nevertheless, it is found that some teachers, besides formulating lesson objectives that focus on content, do not see any relevance in formulating language objectives and lack understanding of how to identify and appropriately write those [75,77,86,90]. Furthermore, teachers assume that students already know certain terms even though they are not yet familiar with them [83].

5.1.3. Pedagogical Knowledge

- *Non-threatening and Appreciative Learning Environment*: Teachers are found to create a non-threatening and appreciative learning environment [81,84,88,89,91], mainly by reducing anxiety so that students dare to express themselves in front of the whole class, e.g., through a peer feedback loop before sharing with the whole class [81,91], valuing students' statements in everyday language [75,84,92], and dealing with mistakes as learning opportunities [84,89].
- *Collaborative Group Work*: Teachers seem to hold a constructivist view as they describe the development of scientific language embedded in social interaction. Therefore, collaborative group work is used by many teachers to foster scientific language production and reduce barriers to speaking as the students feel more confident talking in small groups with their peers [74,75,80,85,91,93]. The exchange in the collaborative group also promotes the negotiation of the meaning of scientific terms and the willingness to speak out in front of the whole class afterward.

5.1.4. Assessment Knowledge

The only study with an explicit focus on assessment is the one by Zolfaghari and Ahmadi [79] (p. 10). It is found that teachers use a combination of continuous and final assessments. The following components of assessment literacy of science teachers are identified: real life application of knowledge, analytic power (e.g., problem solving, reasoning power, linking the issues together), lab experiments, comprehension, theoretical issues, practical issues; understanding figures, diagrams, and tables; and laws and formulae.

In all these components scientific language must play a role; nevertheless, it is not explicated to what extent scientific language matters.

In other studies, only evidence related to formative assessment to assess students' learning and modify instruction can be identified, including (i) the speaking dimension: listening to students as they work in groups [74,82,89,93] and their comments during classroom discussions or as answers to teachers' questions [67,74,78,81,85,93] to evaluate the use of keywords and whether they express themselves correctly; and (ii) the writing dimension: graphic organizers filled in by the students [70,82,85], the summary of a text by students [85], and students' written scientific terms as answers on reading out definitions [84].

To assess a broader range of comprehension, the assessment must include different dimensions of language, especially speaking and writing [70,82,90]. This serves to minimize the issue of language in assessing science as the students cannot adequately express themselves [90]. It appears difficult to differentiate between assessing students' language skills and their conceptual understanding [93]. Another point to mention is the importance for the teachers to monitor students' language performance to adjust instruction as the lesson progresses, ensuring understanding before progressively introducing new terms [78].

Furthermore, studies show that a lack of assessment embedded in classroom instruction can lead to a discrepancy between teacher and student discourse [68,77,94] as, e.g., students hold views about a scientific term that differ from the meaning intended by the teacher. A focus not only on assessing the concept behind the scientific terms but the usage and function of scientific language is found to be nearly absent in science classrooms [77,90,93,95].

5.1.5. Knowledge of Students

Seah and Chan [78] identify the following five realms of science teachers' knowledge about students that are related to addressing the language demands of science, which all other results can be sorted into:

- *knowledge of students' prior knowledge of and about scientific language* [42,70,74,83]
- *knowledge of students' difficulties with scientific language and its use and potential roots of these difficulties* [74,83,90]
- *knowledge of differences in students' abilities across modes of language*
- *knowledge of differences in students' language ability across subject areas*
- *knowledge of students' learning progress in language use* [74,83]

This knowledge does not only refer to knowledge that comes from literature but also includes long-term observations across several groups of learners.

As indicated, teachers need to know about prior knowledge to be able to respond to it appropriately and link new knowledge to it. As reported in the literature, solely making implicit assumptions is not sufficient to elicit students' prior knowledge; some teachers are even unaware of the role of prior knowledge of scientific language when it comes to teaching it [68,75,83].

5.2. Teacher Amplifiers and Filters

Scientific Language Awareness

As explained by Gess-Newsome [28] (p. 34), teachers' beliefs, views about societal goals for schooling, preferred instructional strategies, and preferred organization of subject content influence how knowledge is incorporated into their teaching practice. Additionally, teacher professional knowledge bases can act as an amplifier or filter and thus influence the translation of knowledge into teaching practice. As found by Fulmer et al. [46], teachers with less knowledge about language as an epistemic tool are less likely to recognize the role of scientific language in learning science. It can be followed that the scientific language awareness of the teacher acts as a main amplifier and filter regarding the explicit and conscious teaching of scientific language. As can be derived from the literature, scientific language awareness can be divided into:

- *Grammar/Discourse Norms of Scientific Language* [70,73,74,78,80,81,85,89,93,96]
- *Scientific Terms and their Morphology* [42,70,72,74,77,80–85,87–89,93]
- *Semantic Relationships between Scientific Terms* [42,70]
- *Teaching Scientific Language is a Task of Science Teachers* [85,90]
- *Difference of the Scientific Language Register in Comparison to Other Language Registers* [42,66,74,77,83,85,89,91]
- *Abstractness of the Concepts Behind the Terms* [67,87]

As with content knowledge, there appear to be gaps on the part of teachers concerning scientific language awareness. Teachers are found not to place an explicit focus on scientific language and its characteristics when teaching [67,69,71–73,75,77,86,88,93,95]. It is uncertain whether they feel no necessity to place an explicit focus on scientific language and therefore to talk about scientific language on a meta level, e.g., to tell students how to form scientific sentences or how scientific terms are used, or whether this lack of scientific language awareness stems from poor content knowledge. The lack of science teachers' scientific language awareness leads to a lack of learning opportunities for students as they are not given the opportunity to learn about scientific language and actively engage with scientific language. There is also evidence that teachers themselves are not aware of their word choice and the complexity of scientific language and therefore convey false knowledge through their lack of scientific language awareness, e.g., through using scientific terms in an everyday sense [65–69,74,76].

5.3. Learning Context

5.3.1. Student Attributes

As well as teachers' amplifiers and filters, the learning context serves as a filter when it comes to applying knowledge of teaching and learning the scientific language in practice and thus makes every lesson unique. Most important here seems to be the knowledge about *student attributes* [27]. Regarding scientific language, one can refer again to Seah's and Chan's [78] categorization of the knowledge of students that is related to addressing the language demands of science. Of the five realms, four can also be connected with the learning context as they are influenced by individual students:

- *students' prior knowledge of and about scientific language*, since it cannot be assumed that the students have all the scientific language skills that they should have acquired in lower classes [70,89],
- *students' difficulties with scientific language and its use*, as they occur directly when learning scientific language [93],
- *students' abilities across modes of language*, as, e.g., students may have difficulties with the language of instruction as they are non-native speakers, and thus their language proficiency influences the way of teaching, in general, and scientific language in particular [67,70,72,74,75,77,80,81,85,89,91–94,96], and
- *students' learning progress in language use*, as they develop their abilities in scientific language use over time [74,93]. To elicit students' (scientific) language abilities, it is crucial to draw on assessment knowledge, and in turn, it is important to know about students' attributes to enhance the quality of assessment [79].
- *students' experiences and cultures* are other important issues to be mentioned as a therein knowledgeable teacher is able to connect, e.g., explanations of scientific terms with their experiences [68,70], or to use their home language to help them understand scientific concepts and thus scientific language [96]. Thus, every instructional decision is influenced by the students [74,78].

5.3.2. Curriculum Materials

Another way in which the learning context influences teaching is through curriculum materials, but this depends on the educational system of the country. One way to deal with curriculum materials is to analyze them for language demands to be able to address them accordingly in class [85]. It is also reported that other teachers use pre-made material due to time constraints [75].

5.4. Pedagogical Scientific Language Knowledge

5.4.1. Scientific Language Role Models

An important aspect to be considered when teaching scientific language is that others can act as scientific language role models: on the one hand, the teacher can serve as a scientific language role model [77,89,90]. It is important that the teacher consciously assumes this role. Besides the fact that the teacher can use scientific language explicitly, one can also incorporate scientific language casually to get students used to it [42,89]. On the other hand, students themselves can serve as scientific language role models [89,93].

5.4.2. Development of the Concept before Development of the Scientific Language

An important point that emerges from the literature is the focus on conceptual understanding before introducing scientific language. Therefore, teachers use less scientific and more everyday language or students' home language to help students understand the concepts and ideas within meaningful contexts or real-life examples [75], sometimes through hands-on activities that are carried out first, before slowly abstracting language to scientific language and naming the concept with the scientific term [42,67,70,78,80,87,88,91,92,96]. Another way to make the scientific language more understandable is to explain science in alternate ways (e.g., through analogies) [78,88]. When using analogies, the teacher has to be mindful that students might adopt these analogies in their explanations unreflectively and therefore the teacher should explicitly highlight that these words are inappropriate for describing a more formal scientific process [78].

5.4.3. Making Scientific Terms and Language Explicit

As scientific language is not only the medium through which knowledge is communicated but represents a learning object of its own, it is important to present key scientific terms to students and draw their attention to them, e.g., through graphic organizers, oral discussion, or diagrams and pictures [42,70,74,80,84,89]. Not only presenting the terms, but thematizing the morphological structure of scientific terms [82], e.g., prefixes [72], relations between terms [42], singular and plural as well as abridged and unabridged forms [78], or cognates [70], is an important part of science lessons. Moreover, the correct phrasing of scientific sentences also requires explicit attention [74], as well as the context the terms are used in when they have different meanings in different contexts [91]. One of the goals pursued is also the development of the students' metalinguistic skills [70]. In conclusion, it is important to provide opportunities for students to use scientific terms and language in their talking and writing [74].

5.4.4. Providing a Discursive Classroom

The literature shows that a language-rich and discursive classroom environment [74,80,85,89,90,92,94] is an important point for the development of scientific language. The understanding of scientific language develops only through its extensive use [89]. For teaching scientific language, this means:

- *providing opportunities for students to practice scientific language*: mainly in collaborative and authentic settings by meaningfully engaging with scientific language through language-rich tasks [70,74,85,89,93] by
- *incorporating multiple dimensions of language*: speaking, reading, writing, and listening on different levels (vocabulary, syntax, diagrams, pictures, and discourse), sometimes accompanied by gestures [68,74,85,89,94] and
- *negotiations of term meanings*: individually (e.g., reading texts), with one another in a group (e.g., asking and answering questions, arguing), and the whole group (e.g., discussing) [70,74,89,93] that focus on conceptual learning and connects to what has been learned before.

- *asking questions*: The discourse can be supported through three kinds of teacher questions: (i) lower order thinking questions more in the forms of what-questions as they are less cognitively demanding and produce short answers, e.g., for connecting the actual lesson to previous lessons or to check or recall previously stated information, (ii) higher order thinking questions in forms of why-questions to foster language production and deeper thinking, mostly accompanied by extra time to first discuss in pairs before collected in plenum, and (iii) language-related questions to prompt the use of genre-specific ways of speaking the scientific language and to test lexical understanding [91].

5.4.5. Providing Multiple Resources and Representations

It is important for students to engage with all dimensions of scientific language [9,12]. Therefore, providing multiple resources and different representations of scientific terms and the belonging concepts is important [67,70,75,78,80–83,85,89,90,92]. For example, pictures [74,75,78,80,82], diagrams [78,85,89], graphic organizers and concept maps [70,82,85,89], drawings [67,89], texts [78,83,88], hands-on activities (e.g., experiments), and artifacts [82,83,89,92] are used.

5.4.6. Providing Scaffolds for Scientific Language Development

Since scientific language is new to students, their learning of scientific language should be supported by various scaffolding strategies [42,85]. Besides a non-threatening and appreciative learning environment, scaffolding strategies can be used to foster scientific language production and minimize anxiety. These scaffolding strategies include:

- *oral strategies*, such as, e.g., the teacher uses questioning techniques such as the sequencing of questions or lower and higher order thinking questions [42,70,74,75,89–91,93]
- *visual aids*, e.g., vocabulary sheets with pictures [74,80]
- *written strategies*, e.g., to help students produce scientific text types [75,81] by providing them with sentence frames [74], letting students fill out graphic organizers to highlight connections between scientific terms [70], or helping them create tables and graphs [74]
- *accepting that students use less scientific terms* they are familiar with and reformulating the students' statements in appropriate scientific language [42,67,70,78,80,87,88,91,92,96].

5.4.7. Communicating Expectations Clearly

One aspect that may be important but has not appeared in many articles is to clearly and explicitly communicate the expectation to the students regarding the scientific language. By modeling scientific language, the teacher transports expectations only implicitly [77,89,90], but through a meta-discourse on scientific language, e.g., on constructing claims [74] or explanations [90], the demands on the scientific language are also made clear.

5.4.8. Specific Methods and Tools for Teaching and Learning Scientific Language

A few methods and tools emerge from the literature that seem to be used frequently by several different teachers and thus seem to be promising for teaching scientific language. These will be shortly presented in the following:

- *glossary*: A glossary or vocabulary list is used to secure core scientific terms over lessons so that students have an overview [80,82,84,89]. The explanations and definitions of scientific terms in the glossary can be supplemented with pictures where appropriate [80,82]. Additional forms of the terms or synonyms can also be added and thus foster metalinguistic awareness of the students [82].
- *graphic organizer/concept map*: Graphic organizers are used as a tool to highlight the differences and relationships between scientific terms and therefore develop students' metalinguistic skills [70,82,85,89]. They can also be used to make sense of a complex text [70,85] or to help students formulate scientific sentences [70]. When provided by the teacher, the graphic organizer must be strategically designed during lesson

planning [70,85]. To gain a higher level of clarity, information in the graphic organizer can be color-coded [70].

- *scaffolding written and spoken scientific language*: Another tool to be found in several studies is providing scientific terms, sentence starters, or text skeletons to scaffold the scientific language production of the students [72,75,77,78,80–82,85]. Special attention seems to be paid to the writing of science reports [70,81]. As students are not familiar with scientific texts, the students are also offered assistance in extracting information from texts, e.g., through reading texts together [70], jigsaw-reading, or reading guides [85].
- *gamification*: Gamification of scientific language learning is used to foster students' motivation [82,84,94]. Friendly competition and individual contribution to the group's success emerge as important factors when using games for scientific language learning in the classroom [82,84]. For example, matching activities [82], Quizlets [82], and memorization games [84,94] are used. Particularly detailed was the description of the S4V8 method used by one teacher [84]: Students are allowed four minutes to study their vocabulary lists in their notebooks, then the teacher reads off eight definitions of scientific terms and the students must write the corresponding scientific term down. After reading off the eight definitions, the solution is discussed, students count their right answers and draw a graph with their results over weeks in their notebook. Then the students put their answers in a basket, and the teacher counts up the number of right answers in the class and draws a class graph. For this game, the teacher does not require perfect spelling as mastering the concept is the focus and students' answers are not checked by the teacher [84].
- *digital resources*: Another possibility to foster the motivation of the students and encourage students to learn the scientific language is using digital resources through which a connection can be made to the students' everyday world [75,81,82]. This can incorporate different dimensions of language, as, e.g., students complete sentence puzzles and record themselves reading the sentences [82], listen to the news and write about it concerning the lesson content [75], or discuss scientific topics by prompting with a pop song with an explicit focus on scientific language [81].

6. Discussion

The present systematic review evaluates recent articles on science teachers' knowledge and teaching practices focusing on scientific language to identify elements of pedagogical scientific language knowledge (PSLK) and locate them within the Refined Consensus Model (RCM) [27]. The result is presented in Figure 1.

It is found that the *teacher professional knowledge bases* informing PCK in the RCM are also the knowledge bases informing PSLK (as can be seen as arrows in Figure 1). These knowledge bases—which are namely *content knowledge*, *assessment knowledge*, *pedagogical knowledge*, *curricular knowledge*, and *knowledge of students*—are to be seen as a part of teacher knowledge in general but regarding PSLK with a particular focus on scientific language. As it appears that all the knowledge bases as defined in the RCM by Carlson and Daehler [27] are an essential element of PSLK, these need to be focused on in science teacher education. However, as the teacher professional knowledge bases merge into PSLK, it is also important to interconnect these knowledge bases.

Furthermore, *teacher amplifiers and filters* as well as the *learning context* (which are shown in Figure 1 as transparent circles where the teacher knowledge has to pass through and therefore is influenced by these two factors when forming PSLK) influence the way teacher knowledge is implemented in their teaching practice regarding scientific language and thus PSLK is formed. The main amplifier and filter to be found is scientific language awareness, which plays a crucial role in teaching scientific language as teachers must first consciously assume their role as a linguistic guide of scientific language to be able to form PSLK.

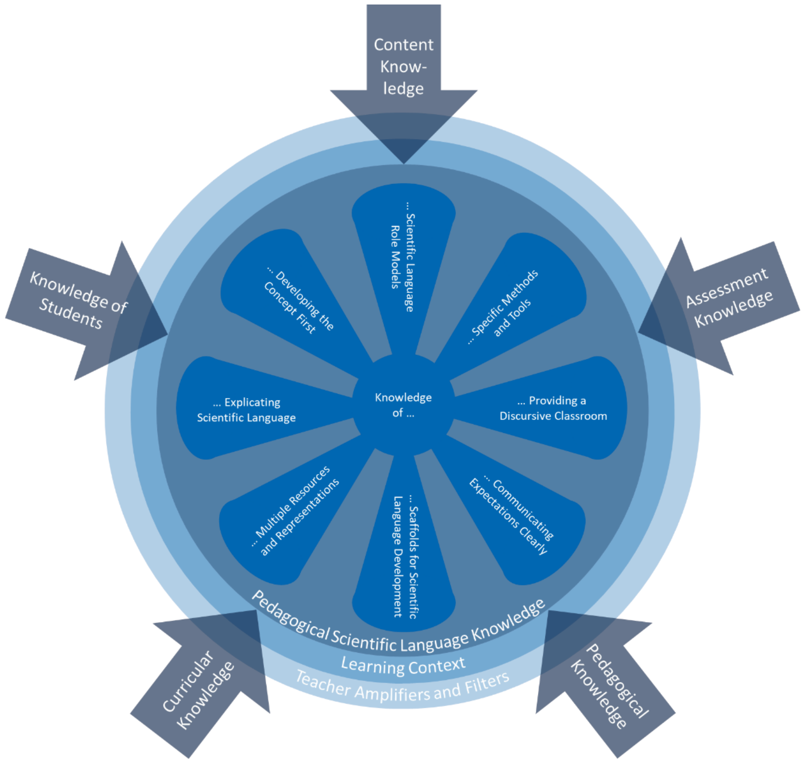

Figure 1. Elements influencing and constituting PSLK.

Additionally, a few *elements constituting pedagogical scientific language knowledge* have been identified, and these are to be found in the middle of Figure 1. To teach scientific language, it seems especially important to act as a scientific language role model. Therefore, besides scientific language awareness, it is important that teachers have general as well as critical language awareness. Only by having (critical) language awareness in general and scientific as well as metalinguistic awareness in particular will teachers actually see the need to focus on (scientific) language during their science lessons. Thus, teachers must themselves see not only as science teachers but also as language teachers. Metalinguistic as well as scientific language awareness is also a premise to being able to make scientific terms and language explicit during science lessons. Another important point of science teachers PSLK appears to be providing multiple resources and representations to enable the students to develop a concept on different representational levels, as the concept has to first be developed before introducing the belonging scientific language. Another crucial point in teaching scientific language is to clearly communicate the teacher's expectations of students in terms of scientific language use. These expectations, however, have to be adjusted to the scientific language abilities of the students. First, teachers should provide several scaffolds to help the students develop scientific language competence. As their competence level increases through multiple opportunities to practice the scientific language on multiple dimensions within a discursive classroom, the scaffolds can be reduced, and the expectations increase.

In addition to the identification of the elements of PSLK (Figure 1), it is noticeable that current research identifies a lack of teacher knowledge of teaching and learning scientific language amongst pre- and in-service science teachers, to only mention a few: Teachers are not aware of the role of scientific language when teaching content as there are no scaffolds provided to help students produce scientific language [75]. There is still great uncertainty about how to support students' scientific language development [97]. It can be said that the quality as well as the quantity of oral interaction in science classes is low and unfocused [12]. This may be caused by the lack of awareness of many teachers of the role of language in learning chemistry [6], and pedagogical knowledge of academic language remains rather limited for many teachers [98]. As Tang and Rappa [36] summarize from research on literacy instruction in science, teachers only have a narrow understanding of scientific language at the simplest level, the vocabulary level, and mostly only emphasize special keywords. Except for scientific terms, there is no responsibility felt for linguistic issues in chemistry classes on the side of the chemistry teachers [99]. In addition to the lack of (critical) scientific language awareness, teachers sometimes struggle with the accurate usage of scientific language in contrast to the everyday meaning of the terms [100] or the meaning of scientific terms themselves [65]. As the research of Meier et al. [101] shows, pre-service teachers often lack extensive knowledge of scientific language and only identify scientific terms as language demands in the science classroom. The research of Carrier [102] brings to light that pre-service teachers misuse scientific terms and even provide incomplete meanings. To summarize, the results of the studies included in the present systematic review as well as other studies (e.g., [45]) reveal a need for the (more) explicit focus on scientific language and the teaching and learning of it in science teacher education.

However, the crucial element to fostering pedagogical scientific language knowledge of (future) science teachers is science teacher educators. Therefore, one of the first steps to foster PSLK would be to sensitize science teacher educators in terms of scientific language. By them recognizing the role scientific language plays in their teaching and how scientific language is used by them (e.g., reflective usage of and explicating lab jargon), science teacher educators would act as role models for the reflective usage of scientific language in teaching—according to the motto, 'practice what you preach' [103]. However, this is not only necessary on the part of science education seminars, but on the part of general science seminars, too. By giving the pre-service teachers the opportunity to witness the reflective scientific language usage and reflect on their own scientific language usage, their scientific language awareness can be fostered. Another possibility to foster scientific language awareness as well as curriculum knowledge, as they both influence PSLK, is to let pre-service science teachers analyze the curriculum as well as curriculum material with regard to scientific language. By this, they might experience consciously for the first time how dense scientific language is used in, e.g., science books and that curriculum material can hardly be used without checking it for scientific language. It is especially necessary to make pre-service science teachers aware of the difficulties, students might have with scientific language, as the pre-service science teachers might adopt the traditional methods they experienced as schoolkids otherwise [64,102,104]. However, it must be ensured that (future) science teachers do not only reduce the demands of scientific language but foster the productive usage of it [90]. Content knowledge of science in general, but of scientific language in particular, as a kind of disciplinary literacy [48], is another knowledge domain to be fostered with regard to fostering PSLK. This knowledge of scientific language must be acquired at three different levels: the vocabulary, grammar, and genre level [36], and can be further divided into "(a) knowledge about the distinctive grammatical and structural features of scientific language as compared to other disciplines and (b) the functions of these language features in constructing and arguing scientific propositions and knowledge claims" [97] (p. 1072). Additionally, it could be helpful for (future) teachers to obtain methods to teach scientific language. Testing these methods in practice could be a part of the school internships, as practice is another crucial element of developing PSLK. Afterward, the practical experiences could be discussed in seminars that accompany the internships. Therefore, it would be helpful to know more about specific methods science teachers use to teach scientific language as less is known about the practice of science teachers when it comes to teaching and learning the scientific language yet [52].

As the focus of 15 included articles in the systematic review is on SLLs, the question arises whether the language of instruction in general and the scientific language in particular should be treated separately or if they go hand in hand so that there is no sharp line to divide scientific language from the language of instruction. Even if the students are native speakers, other factors such as, e.g., their socio-economic status, can influence their (scientific) language proficiency and therefore they need more support in learning the scientific language. Many articles are excluded because they focused on language and literacy development in general and there is no clear distinction between language and scientific language. It is to question whether the fact that scientific language is also a problem for "mainstream" students is not sufficiently addressed.

However, this systematic review already reveals a few principles for teaching scientific language and methods and tools that can be used to foster scientific language when teaching. As most of the included studies in this review are qualitative in nature and often case studies, generalization of the results is difficult—especially with the focus on different languages spoken in the different countries (e.g., English, German, Spanish, French, . . .). Still, more needs to be known about science teachers' PSLK. This could be helpful to integrate best practices into teacher training. As Fulmer et al. state [46], knowledge of language as an epistemic tool is not acquired through practice alone but opportunities to practice in school are necessary to develop an awareness of scientific language demands and practices of teaching scientific language (e.g., [29,30,73,85]), it is important to give especially pre-service science teachers the opportunity to learn the theory but then to practice and reflect on their practical experiences as a part of science teacher education programs. Another point that could be of interest and answered by further research in this field is whether PSLK is discipline-specific in general or if there appear to be some topic- or content-specific elements as well.

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Appendix A. List of the 35 Selected Articles for the Systematic Review in Alphabetical Order

- Afitska, O. Scaffolding Learning: Developing Materials to Support the Learning of Science and Language by Non-Native English-Speaking Students. *Innovation in Language Learning and Teaching* **2016**, *10*, 75–89.
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Appendix B

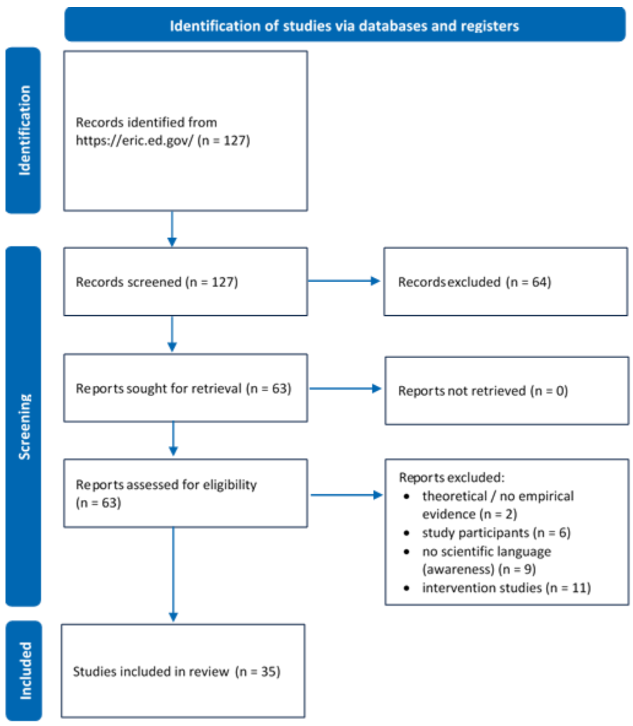

Figure A1. PRISMA Flow-Diagram.

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