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Exploring Pre-Service Chemistry Teachers' Pedagogical Scientific Language Knowledge

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Abstract: *Chemish*, as the scientific language of chemistry, is essential for communicating in and understanding chemistry. At the same time, Chemish is one of the major difficulties in teaching and learning chemistry in the school context. Although in recent years the importance of language in general and scientific language in particular has been pointed out and much research has been carried out on these topics, less is known about (pre-service) chemistry teachers' knowledge of teaching and learning the scientific language in chemistry classes. Thus, the research on *Pedagogical Scientific Language Knowledge* (PSLK) is missing. As this knowledge is crucial for (future) chemistry teachers to teach chemistry, in our survey, we seek to evaluate the extent of 41 pre-service chemistry teachers' PSLK. The answers are analyzed using qualitative content analysis. Results show that pre-service chemistry teachers' content knowledge resembles the level of knowledge for higher secondary schools. Likewise, the pre-service chemistry teachers have a lack of incisive pedagogical content knowledge: although recognizing problems within Chemish, the pre-service chemistry teachers hardly address those and do not focus on the characteristics of Chemish while explaining scientific terms. On this basis, implications for further university chemistry teacher education and research will be drawn.

Keywords: Pedagogical Scientific Language Knowledge; qualitative content analysis; Chemish

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1. Introduction

The overarching goal of science education in general—and chemistry education in particular—is to promote scientific literacy and thus to enable students to engage as responsible citizens with science-related topics [1,2]. In the school context, language is the key to communicating knowledge. In science classes, understanding scientific language is a premise to become scientifically literate. Therefore, understanding scientific language as well as correct and addressee-oriented use of it are key competences for participating in chemistry class and essential for the acquisition of scientific literacy. Since understanding and using the scientific language of chemistry—the *Chemish* [3]—are competences to be acquired in chemistry class, chemistry teachers are responsible to support students in acquiring and using Chemish. To put it in the words of Laszlo [4] (p. 1682): "Chemistry teachers are linguistic guides, they are interpreters. They teach their students how to craft well-formed chemical sentences". In conclusion, chemistry teachers must be adequately prepared to address their students' difficulties in learning and using Chemish and to make scientific content accessible to all students. To do so, chemistry teachers must be confident in their use of Chemish. This requires first and foremost a fundamental knowledge of Chemish and concepts behind the language (content knowledge), as well as an awareness of Chemish and its characteristics. Furthermore, they need to possess knowledge on how to teach and learn Chemish. Since research on (pre-service) chemistry teachers' knowledge of teaching and learning Chemish is rare, this study seeks to evaluate the extent of knowledge about teaching and learning Chemish pre-service chemistry teachers already possess to draw conclusions for further university chemistry teacher education and research.

2. Theoretical Background

Language and literacy in general are the prerequisites for the acquisition of knowledge [5]. That becomes even more apparent when thinking of different classroom activities: every activity is essentially bound to at least one dimension of language—as they are reading, writing, listening, and talking [6]. Language serves concurrently as a goal of and a vehicle in education [7], even more so in science class as there is an additional language, the scientific language, which must be understood to participate in science class [6,8–10]. Postman and Weingartner [11] stated, that "almost all of what we customarily call 'knowledge' is language, which means that the key to understanding a subject is to understand its language" as cited in [9] (p. 3). Thus, knowing the scientific language enables students to think scientifically [12]. In more recent curricula, the role of scientific language in learning science has been taken into account to the extent that it has become an explicit goal of science education in several countries, e.g., [13–17].

Focusing on language, Yore and Treagust [10] describe the problems students may have in chemistry class as a three-language problem: students must switch between home language, instructional language, and scientific language. Thus, in chemistry classes, the usage of Chemish [3] is a special obstacle for learning [9]. Students' challenges with Chemish itself can occur because, according to Lemke [18], the scientific language has its own semantics, supplemented by its grammar, rhetorical structures, and figures of speech. Additionally, one can examine the features of scientific language at three levels: the vocabulary, grammar, and genre level [19]. Finally, Chemish includes three different components: macroscopic (e.g., substances and phenomena), microscopic (e.g., molecules and atoms), and symbolic (e.g., formulas and equations) [20,21].

As described by Childs et al. [6] as well as by Quílez [22], this complexity of Chemish is very high and the language is multifaceted due to unfamiliar, sometimes polysyllabic technical terms which are often based on Greek or Latin; some technical terms are used only a few times in chemistry education in school over years; some technical terms have different meanings in different contexts; there are special verbs (e.g., explain, describe) and logical connectives; additionally, there is the symbolic language as well as the use of diagrams, and it contains parts of mathematics. Besides the technical words, problems can occur since non-technical words are used in science in another way than in everyday language (e.g., the word 'solution') [23]. It is therefore important to incorporate students' understanding of the term into the lesson and expand or modify the meaning in relation to Chemish. If this transition from understanding the term in everyday language to Chemish does not take place, teachers and students could use the same word but connote it with different meanings, which leads to misunderstandings and buildup of misconceptions on the side of the students.

Quílez [22] stated that the barriers for students learning Chemish are diverse: (i) they lie in teaching tools and materials (e.g., the way chemistry texts are written, the language of chemistry exam questions, and how problems are expressed), (ii) they are influenced by chemistry teachers' preparation for teaching scientific language and their awareness of the barriers [22], and (iii) they lie within the above-named characteristics of Chemish. Thus, Chemish can be an issue that hinders students' enculturation in the discipline of chemistry [24], and consequently hinders them from becoming scientifically literate.

Since students are not innately familiar with Chemish and need to first acquire it, learning Chemish is very often compared to learning an additional language [9,25–29]. However, this does not mean that learning Chemish is equal to second language acquisition. In second language acquisition, the native language serves as a reference; in contrast, in the acquisition of scientific concepts and, therefore, the scientific language, the concept and the language must be acquired simultaneously [30]. Rincke [31] confirms this way of scientific language acquisition for physics education. This way of acquiring Chemish results in a double challenge of "increased cognitive demands embedded in meaningfully engaging in the STEM practices [that] are accompanied by increased linguistic demands associated with expressing one's ideas about these practices" [32] (p. 363). Following this double challenge and keeping in mind the named characteristics of Chemish, chemistry teachers need to be aware of (i) characteristics of Chemish, (ii) students' knowledge about certain words and concepts, and (iii) the methods and tools to teach Chemish. Keeping this in mind, chemistry teachers need to consider the high degree of accuracy in using Chemish in their classes.

Summing up the named requirements, chemistry teachers need to act as linguistic guides [4] for their students to enable them access to the scientific language and thereby participation in the chemistry class. Hence, chemistry classes become language classes focusing on Chemish [22]. According to Kulgemeyer [33], thematizing the differences of everyday and scientific language and considering students' alternative conceptions and preconceptions according to the scientific language are important when teaching science. However, approaches that focus on the "hidden conventions" of scientific language, and thus on metalanguage, "that govern the way language is used to produce and communicate scientific knowledge" are missing [19] (p. 1312). Metalanguage in the context of science therefore "refers to the technical terms for talking about scientific language" [19] (p. 1312). However, what knowledge do chemistry teachers need when it comes to the teaching and learning of Chemish?

To categorize different types of teacher knowledge, Shulman [34,35] distinguishes between content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK), which is "a special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" [35] (p. 8).

Galguera [36] specified the PCK in terms of academic language and first proposed the need for teachers to develop *Pedagogical Language Knowledge* (PLK) as PCK for academic language development rather than to prepare teachers to teach English Language Learners (ELLs). This knowledge includes creating opportunities purposefully for the development of language and therefore literacy in and through teaching content. Crucial components of PLK are *language awareness* [37] and *metalinguistic awareness* [38], as well as *critical language awareness* [7,39,40]. *Language awareness* defines explicit knowledge about language and perceiving and using language consciously. *Metalinguistic awareness* is defined "as conscious knowledge of the formal aspects of the target language (e.g., grammar)" [38] (p. 248). *Critical language awareness*, on the other hand, refers to the social, political, and ideological aspects of language, while language practices are seen to sustain and reproduce power relations. In this sense, language proficiency can be seen as empowerment for participation [40]. Finally, a crucial point for developing PLK are opportunities to practice for the teacher to pay active attention to (critical) language and metalinguistic awareness, as well as language usage.

According to Galguera [36], Bunch [41] defined PLK "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" [41] (p. 307) with a special focus on ELLs. This knowledge is different from the PCK of second language teachers and that of mainstream teachers on their subject area(s). Developing PLK in the sense of Bunch [41] means focusing primarily on developing critical language awareness. Additional attention should be paid to "linguistics, SLA [Second Language Acquisition], bilingualism, and other language-related knowledge bases" [41] (p. 307). Besides these rather theoretical knowledge bases, putting the knowledge into practice is essential, as the notion of language as action serves as an overarching principle [41].

Several other authors have also recognized the importance of teaching language in content areas and therefore a need for a special kind of teacher knowledge as well. Only to mention a few approaches: Lucas and Villegas [42] claim a need for *linguistically responsive teachers* to help ELLs learn the content. Turkan et al. [43] present a theoretical framework in *Disciplinary Linguistic Knowledge* (DLK) to teach the content of a specific discipline to ELLs. Fulmer et al. [44] describe a need for *teachers' knowledge of language as an epistemic tool* in science classes. All the approaches [36,41–44] have in common that teachers need to know the linguistic features spoken in their content area(s), be aware of these features, and actively and purposefully incorporate that discipline-specific language into classroom activities. The crucial component and overarching principle are, however, to put the knowledge and attitudes into practice. As the authors of the approaches on teaching language in content areas already stated, only in this way the full knowledge will develop over time. However, except the approaches of Galguera [36] and Fulmer et al. [44], all approaches focus solely on teacher knowledge for teaching ELLs. However, because Chemish is challenging not only for second language learners but for all learners, a special type of chemistry teacher knowledge on teaching Chemish is needed.

Starting from the concept of PLK, it can be concluded that chemistry teachers need more than PCK and CK (and also PK) for teaching Chemish—and not separately, as it is mostly taught at German universities. In line with Ollerhead [45], we state that chemistry teachers must develop professional knowledge with the focus on Chemish: *Pedagogical Scientific Language Knowledge* (PSLK). PSLK was defined by Markic [46] (p. 181) as "teachers' Pedagogical Language Knowledge (PLK) with the focus on the scientific language of chemistry". Developing PSLK means acquiring the knowledge and competences mentioned below in theory, but the crucial point here as well as at the other approaches is to put the knowledge into practice. To be able to put the knowledge into practice, however, (critical) language awareness as well as metalinguistic awareness are necessary regarding Chemish.

Since CK and PCK are essential for the teachers to meet students' needs when learning Chemish, PSLK can be seen as—speaking in the words of Shulman—an amalgamation of CK and PCK regarding Chemish. By this, we mean that besides the CK on different chemistry topics and concepts the teachers must also have CK on Chemish, more precisely at two levels: (i) on the vocabulary level to understand the meaning of the words and the concepts behind the words, and the connections to other related topics; and (ii) on the meta-level in terms of the special semantics, grammar, rhetorical structures, rules of nomenclature, and different representational forms, as well as to identify differences in the meaning of words used in everyday language and scientific language. Therefore, science teachers in general and chemistry teachers in particular must have a clear understanding of the meanings of terms used and different speech genres [47]. In part, PSLK is tied to the scientific vocabulary and therefore specific content areas, but in part, PSLK focuses on the characteristics of Chemish and therefore is also universally applicable to different content areas regarding, e.g., the different components, and can therefore be seen more as a cross-topic principle for chemistry education. Since the PSLK includes the knowledge to put the CK into practice, it can be in part equated with the PCK regarding Chemish. Therefore, along Shulman's [34] definition of PCK, the PSLK also includes knowledge on (i) the most comprehensible representations of content taking into account the Chemish and (ii) students' preconceptions and misconceptions of different scientific terms and associated problems in learning Chemish at both beforementioned levels. The connection of different teacher knowledge domains for teaching and learning Chemish is to be found in Figure 1.

A premise to being able to develop PSLK is to develop language awareness, metalinguistic awareness, as well as critical language awareness in general and additionally with the focus on Chemish. This enables one to pay explicit attention to the usage of Chemish when teaching. Therefore, metalinguistic awareness and metalanguage (as parts of PSLK) are needed to identify the special linguistic features of scientific language and to be aware of and be able to disclose linguistic choices made to communicate meaning. Another aspect of science and therefore chemistry teachers must be aware of is the importance of knowing (about) the scientific language which includes "(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" [48] (p. 1072).

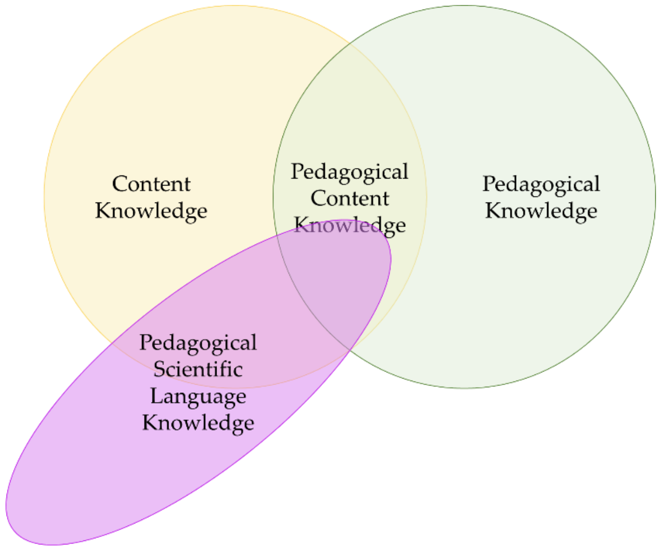

Figure 1. Connection of the different teacher knowledge bases with PSLK.

Research on the Knowledge of Scientific Language of (Pre-Service) Science Teachers

The research on pre- and in-service chemistry teachers' Pedagogical Scientific Language Knowledge is still rare. To give a better picture of existing research, we will also focus on studies and information on pre- and in-service science teachers' knowledge in this area. Current research identified several problems with the scientific language amongst pre- and in-service science teachers, to only mention a few: There is still great uncertainty in how to support students' scientific language development [48]. It can be said that the quality as well as the quantity of oral interaction in science classes is low and unfocused [49]. This may be caused by the lack of awareness of many teachers according to the role of language in learning science [50], and pedagogical knowledge on academic language remains rather limited for many teachers [51]. As Tang and Rappa [19] summarized research on literacy instruction in science, teachers only had a narrow understanding of scientific language at the simplest level, the vocabulary level, and mostly only gave emphasis on special keywords. Besides the scientific vocabulary, there is no responsibility felt for linguistic issues in chemistry classes on the side of the teachers [52]. As the research of Meier et al. [53] shows, pre-service teachers often lack extensive knowledge of characteristics of scientific language and only identify scientific vocabulary as language demands in the science classroom, especially at the beginning of their teacher education program. In addition to the lack of (critical) scientific language awareness, teachers sometimes struggle with the accurate use of scientific language in contrast to the everyday meaning of the words [54] or the meaning of scientific words themselves [55]. The research of Carrier [56] brought to light that pre-service teachers misused scientific words and even provided incomplete meanings. However, less is known about the pedagogical practices when it comes to the teaching and learning of scientific language in science classes. According to Kelly [57], it is, therefore, necessary to document current practices and language use in science education aiming to implement changes in science teacher education regarding how scientific language is interpreted and used.

3. Research Questions

Starting to develop pre-service chemistry teachers' PSLK it is important to depicture the current status quo of it. Thus, the present study is guided by the research question: *'What is the extent of pre-service chemistry teachers' Pedagogical Scientific Language Knowledge?'*

This is to serve in the meaning of diagnostics for the conception of an innovative seminar unit for university chemistry teacher education.

As explained above, CK as well as PCK are necessary for chemistry teachers to possess aiming to identify students' challenges with Chemish and to deal with these challenges adequately. Since less knowledge about the characteristics of PSLK exists to this day, the focus of the present study is on those knowledge domains as part of PSLK related to specific scientific language and thus concepts.

Our study is guided by the following sub-questions:

1. What is pre-service chemistry teachers' content knowledge of certain scientific terms?
2. What difficulties do pre-service chemistry teachers mention that students may have with certain scientific terms?
3. How do pre-service chemistry teachers explain certain scientific terms to their future students of a certain grade level in form of fictitious explanations?

The first question focuses on the pre-service teachers' CK on different scientific terms, the second question focuses on the PCK of the pre-service teachers, and the third question focuses on pre-service teachers' ability to put their CK and PCK into practice in the form of an explanation to students.

4. Materials and Methods

4.1. Instrument

Since the construct of Pedagogical Scientific Language Knowledge is a fairly new approach that has not yet been analyzed in-depth and therefore no evaluation tools to answer the question of the extent of pre-service chemistry teachers' PSLK exist yet, a qualitative study was conducted to specify the characteristics of Chemish already considered without a seminar unit explicitly on teaching and learning Chemish. The following three tasks should be answered in several sets on different scientific terms (X) within a questionnaire:

1. Define the term X.
2. What difficulties might students have with the term X?
3. How would you explain the term X to students in grade Y?

Thereby, the X is representative for the scientific terms and concepts behind them: (i) substance, (ii) element, (iii) reaction, (iv) oxidation, (v) neutralization, (vi) particle, and (vii) air. The grade level Y is based on the competences in the curriculum for the school type pre-service chemistry teachers will be teaching in [13,58]. Due to different study programs (primary and secondary school), two different questionnaires are constructed regarding the included scientific terms (terms for both courses: substance, element; terms for primary only: particle, air; terms for lower secondary only: reaction, oxidation, element). All three questions concerning one scientific term were shown simultaneously on one page of the online survey so that the pre-service chemistry teachers could revisit the answer(s) to the previous question(s).

The first task explicitly refers to the pre-service teachers' definition and not in terms of the school context in order to be able to evaluate the CK on the scientific terms of the pre-service teachers.

The second task is intentionally general and not related to the Chemish, as the goal is to find out if the pre-service chemistry teachers are aware that Chemish can be a difficulty when learning chemistry.

For the third task, the focus on explaining is chosen because explaining can be considered as one core teaching practice of science teachers [59]. Formulating explanations for fictitious others has been reported by Lachner and Neuburg [60] as a constructive learning activity since the pre-service chemistry teachers need to adapt their explanations to the needs of the fictitious students and transform their knowledge in a way that the information gets tangible to the students. Constructing a subject-adequate explanation requires sufficient CK that is mediated by PCK on the topic, which has a positive influence on explaining performance [61–63]. Therefore, the given grade level means for the pre-service chemistry teachers to adapt the explanation to the level of the students (language use and content level), consider possible preconceptions and (future) misconceptions, and different representational levels where appropriate, think about the structure of the explanation and reasoning, and consider the use of examples, experiments, analogies, etc. [62,64]. One difficulty when explaining is that the pre-service chemistry teachers must be aware that language itself can be difficult for students so that the pre-service chemistry teachers use (scientific) language consciously, which becomes apparent through the clarity, coherence and cohesion, sequence, and correctness of the explanation [64]. Likewise, it becomes evident through explanations if the pre-service chemistry teachers already possess PSLK as they consider characteristics of Chemish and make them explicit while explaining [19].

The answers to the scientific terms are distributed as follows: substance (N = 41), element (N = 22), reaction (N = 24), oxidation (N = 24), neutralization (N = 24), particle (N = 17), and air (N = 17).

4.2. Sample

The sample consists of 41 pre-service teachers participating in three chemistry education seminars during fall 2020. All the pre-service teachers study chemistry in their program in Germany. Out of 41 pre-service chemistry teachers, demographic data of six are missing. Of the other 35 pre-service chemistry teachers, 19 are primary science pre-service teachers and 16 are secondary pre-service teachers. All the participants decided to study teacher track from the very first day of their tertiary education. During primary science teacher education, pre-service teachers study primary science courses and can choose a major in either biology, chemistry, physics, or technology. Primary science courses are equally distributed through the bachelor's and master's programs. During secondary chemistry teacher education, pre-service teachers study another subject next to chemistry. The focus of the bachelor's program is on content, only about 14% of the chemistry courses are on chemistry education. In the master's program, about half of the courses are on chemistry education. Subject courses are both for primary science as well as pre-service teachers for secondary schools offered. The internship at school is part of the bachelor's program for primary science teachers, for secondary chemistry teachers it is part of the master's program. In total, 23 of the pre-service teachers are bachelor's students (16 primary, 7 secondary) and 12 are already master's students (3 primary, 9 secondary). The average age is 23 years (SD = 1.9). A total of 14 out of 35 pre-service teachers already completed a 4-month internship in a local school (9 primary, 5 secondary). Three of the pre-service chemistry teachers are non-native German speakers.

4.3. Analysis

The data analysis is based on qualitative content analysis according to Kuckartz [65]. In the following, the construction of the categories, as well as the evaluation of the results, will be described in detail. The answers are coded independently by two researchers. Intersubjective agreement is reached throughout the coding process by discussing and confirming the interpretations of each other. Any ambiguities are discussed and resolved [66]. Through this process, categories are defined more precisely when needed.

For the first task, four different categories are developed, based on the levels of proficiency [67] but focusing on the knowledge to be acquired from different educational levels. These categories were constructed deductively from the curricula [13,68] and books for lower and upper secondary [69–73], as well as university chemistry education [74,75], to classify the CK of the pre-service chemistry teachers for the scientific terms asked in the questionnaire. Additionally, the experiences of one upper and two lower secondary chemistry teachers and one university chemistry teacher educator are considered. For the novice knowledge level, people without scientific backgrounds from the researchers' social environments are asked about their understanding of the terms. The four levels constructed are:

- *Novice knowledge* (includes everyday knowledge and preconceptions, as well as misconceptions);
- *Intermediate knowledge* (knowledge that can be acquired according to the curriculum of lower secondary schools);
- *Advanced knowledge* (knowledge that can be acquired according to the curriculum of upper secondary schools);
- *Superior knowledge* (knowledge that can be acquired in university chemistry teacher education program).

In some cases when pre-service chemistry teachers' answers possess characteristics of two levels, the answer was always rated on the higher level.

As an example, the evaluation pattern of the scientific term "particle" can be found in Table 1. Since the German and English languages have different characteristics, parts of the translations may not be comprehensible. This is mainly due to the different connotations of the term in German and English.

Table 1. Evaluation pattern for the analysis of the definition for the term "particle".

Category	Novice Kowledge	Intermediate Knowledge	Advanced Knowledge	Superior Knowledge
Description	Small pastry, component	There are different kinds of particles (atoms, molecules, ions) that have different masses and sizes. Particles of different substances differ from each other. Depending on the state of aggregation, the distances between the individual particles of a substance differ. According to an atomic model (proton, electron, neutron, nuclear shell model, shell model, outer electron, ion formation, noble gas configuration), the structure of atoms and ions can be explained.	According to an atomic model (electron energy levels, ionization energy), the structure of atoms and ions can be explained.	There is vacuum/matter-free space between particles/atoms. Orbital model.

For the second question, the categories are developed deductively and inductively. According to Taber [76] and Barke et al. [77], one category for preconceptions and one for misconceptions is developed. The category for preconceptions is included in the broader category *polysemy* during the process. This decision is made on the basis that all preconceptions mentioned are related to the polysemy of the terms. Other categories that result from the process are *no conception of the term so far*, *abstractness*, *complexity*, and *no difficulties*. The description of the categories can be found in the evaluation pattern in Table 2. More than one category can be coded in one answer.

For the third question, categories with three different levels are developed deductively and inductively based on the evaluation patterns of Cabello and Topping [64], Marzabal et al. [62], and Sevian and Gonsalves [63] focusing on scientific language. The process results in the following categories: *appropriate for the addressee (students of grade Y)*, *scientific terms*, *the correctness of the content*, *analogies/metaphors*, *examples/experiments*, *polysemy*, and *difficulties mentioned beforehand are addressed*. The evaluation pattern is to be found in Table 3. The explanations are analyzed with regard to each of the following categories. A category can be coded in three different ways: (+) addressed in a positive/appropriate way, (−) addressed in a wrong/inadequate way, and (0) not evident from the answer.

Table 2. Evaluation pattern for the analysis of the mentioned difficulties.

Category	No Conception So Far	Polysemy	Abstractness	Complexity	Misconceptions	No Difficulties
Description	The students have no idea of the term so far. There are no difficulties because the students do not know the word yet. Scientific term is a foreign word.	Students may have issues due to polysemy associated with the term. Students already have preconceptions. Students know the term from everyday life.	The term is not tangible, not observable per se, theoretical concept that is difficult to imagine.	Wide-ranging concept that may include other (difficult) scientific terms and concepts.	Misconceptions are created by intentionally inadequate treatment of the concept or didactic reduction.	There was no example.

Table 3. Evaluation pattern for the analysis of the explanations.

Category	Appropriate for the Addressee (Students of Grade Y)	Scientific Terms	Correctness of the Content	Analogies/Metaphors	Examples/Experiments	Polysemy	Difficulties Mentioned Beforehand Are Addressed
Description	The terms/concepts used can be assumed to be known according to the curriculum and the language level is appropriate for the intended grade level.	Scientific terms, if used in the answer, are used correctly.	The scientific term is explained correctly and appropriate for the curriculum of grade level Y.	The explanation contains an analogy, metaphor, simulation or model.	The explanation includes an example or experiment.	The polysemy of the scientific term is addressed in the explanation, e.g., already known meanings of the term are taken up.	All difficulties mentioned beforehand are addressed in the explanation.

5. Results

The results show that most of the definitions of the scientific terms (49%) are at the *intermediate knowledge* level, which is knowledge to be acquired in lower secondary schools. Another 36% of the answers are at the *advanced knowledge* level (upper secondary level). It is to notice that pre-service chemistry teachers do not define the scientific terms at the superior, i.e., the university level. In total, 15% of the answers are coded as *novice knowledge*, which means everyday knowledge and preconceptions. The answers are often limited to only a part of the meaning of the terms due to the unawareness of their word choice which often resulted in incorrect or incomplete definitions (e.g., "A reaction takes place when *one* substance is turned into something else." [reaction, TA0506]).

Regarding the difficulties that students may have with the scientific terms, the *polysemy* of the term is the most named difficulty in 56% of the answers. Especially for the terms *substance* (95%), *reaction* (83%), and *particle* (59%), most of the pre-service chemistry teachers mention polysemy (e.g., "The polysemy of some words in German is difficult. In physics, a particle means something different (as a content) than in the dominant everyday language." [particle, KA0404]). Although some pre-service chemistry teachers are aware of the polysemy of terms often used in everyday life, many pre-service chemistry teachers are not yet aware of the polysemy of terms that are rarely used in everyday life but the chemistry context.

Three out of forty-one pre-service chemistry teachers stated that there may be *misconceptions* regarding the terms *oxidation* and *neutralization* caused by using the scientific term with several meanings within chemistry or caused by didactic reduction that can result from teaching with the spiral curriculum. One of the three pre-service chemistry teachers identifies misconceptions as a potential problem with both terms, the other two only with one of the terms. Besides the polysemy, no other characteristics of Chemish—as could be the use of symbols, the different representational forms—are named as difficult.

Another difficulty mentioned in 16% of the answers is the *complexity of the concept* (e.g., "One encounters other terms that would need to be defined, such as 'substance'. [. . .]" [reaction, BI2102], or "[. . .] broad and extensive term" [element, FL1112]). This relates to PSLK in so far that the pre-service teachers are aware of the links to other scientific terms and concepts.

The *abstractness of the concept* (28%) and the fact that the students have *no conception of the term so far* (13%) at first glance have nothing to do with the characteristics of Chemish. However, almost all answers refer either to the microscopic component of the Chemish [21] at which students have difficulties imagining (e.g., "It is difficult to imagine how electrons are removed since this cannot be observed directly with the eye." [oxidation, KA2708]) or to a lack of prior knowledge and the difficulty in finding synonyms for scientific terms the children already know (e.g., "It is difficult to find a synonym or a similar description. Students didn't have any conscious contact with substances and therefore probably cannot imagine anything about substances." [substance, AN0712]).

After defining the scientific terms and identifying the students' possible difficulties, the pre-service teachers are asked to explain the scientific terms to fictitious students in a certain grade level. It is to note that the given answers are very short, often just one sentence and more in a form of a definition than an explanation. In some cases, only a description of what the explanation would look like is given, so it is not the explanation itself that can be analyzed. Thirteen explanations are not coded because (i) they are not about the scientific term but the meaning of the term in an everyday context (five) or (ii) they are missing because the pre-service chemistry teachers did lack the knowledge to explain the term (eight) (e.g., "I would have to look at the definition again first" [substance, MO0307]).

Although pre-service chemistry teachers are aware of many difficulties according to the question before, these difficulties are addressed fully in only about a third of the explanations.

A way to deal with the *abstractness of the concept* or the fact that students have *no conception of the term so far* could have been to explain vividly and use experiments or analogies. Thus, we can conclude that the explanation should pay much closer attention to the use of language and visual support through, e.g., analogies or experiments. However, out of 65 answers that stated *no conception of the term so far* and *abstractness of the concept* in the question about the students' difficulties, only in 24 explanations either analogies/metaphors or examples/experiments are used.

Similar to this, although *polysemy* is the most named difficulty it is addressed rarely in the explanations (15%). When addressing the polysemy, the pre-service chemistry teachers often solely casually mention that there is a difference in the meaning in everyday life and the chemistry context by adding the context, and not in taking up the everyday meaning to expand or change it in the context of chemistry and transform it into Chemish. Interestingly, in two of the explanations, the polysemy of the scientific terms is addressed through mentioning the context but has not been named as a difficulty beforehand.

About a third (35%) of the explanations are coded as technically incorrect. It is noticeable that, on the one hand, pre-service chemistry teachers have misconceptions (e.g., "[. . .] For example, you put salt into water and stir (energy is put in), the salt dissolves in the water. The initial substances change and a new substance is created (saltwater)" [reaction, CO1104]) and on the other hand they do not use language consciously to avoid misunderstandings (e.g., "In order to divide substances according to their properties, they are divided into elements." [element, SU0110]).

6. Discussion

The present study evaluates the extent of pre-service chemistry teachers' Pedagogical Scientific Language Knowledge (PSLK) intending to adapt university chemistry teacher education. For this, we discussed the characteristics of PSLK and see the dependents of this kind of knowledge with teachers' pedagogical content knowledge as well as their content knowledge regarding scientific language.

The results of our study show that the majority of the pre-service chemistry teachers possess content knowledge which is comparable to the one of higher secondary education. Furthermore, the majority of the pre-service chemistry teachers in this study see polysemy as a major difficulty the students could have according to Chemish when learning new scientific terms in chemistry. However, the characteristics of Chemish were not given much attention in the pre-service chemistry teachers' explanations.

In general, we need to say here that the pre-service chemistry teachers' responses focus only on specific scientific terms, it should also be noted that the survey method does not reveal the complete scope neither of the pre-service chemistry teachers' CK nor their PCK. This is also influenced by the sometimes short answers given by the pre-service chemistry teachers.

Regarding Chemish, it is interesting to see that except for polysemy, no other characteristics of Chemish are named as difficult, although the symbolic component is used in the pre-service chemistry teachers' definitions and the different components can cause difficulties when learning chemistry. These results about the low extent of pre-service chemistry teachers CK and PCK stand in line with the results from Hilfert-Rüppell et al. [78]. Considering pre-service chemistry teachers' explanations of the scientific terms to fictitious students, it was interesting to see that pre-service chemistry teachers seemed to have problems transferring the identified difficulties into explanations that address these difficulties. Focusing on the consideration of student misconception or using experiments/demonstrations to construct explanations, Cabello et al. [79] conclude similar results. They were also able to show that several difficulties were named.

Based on the above, the question must be asked whether the pre-service chemistry teachers do not yet have sufficient skills to deal with the difficulties or if they do not see the connection between the students' difficulties with the scientific term and the importance to address those in their explanation.

To summarize, this survey revealed a need for explicit university chemistry teacher education when it comes to teaching and learning Chemish. For further work, this means that part of the chemistry teacher education program should also be the structure and characteristics of the Chemish. Likewise, since (critical) language and metalinguistic awareness should be a part of chemistry teachers' PSLK, it remains to be said here that the use of Chemish, as well as laboratory jargon, would also have to be actively addressed on a metalinguistic level, which does not yet happen in most cases. Especially in general chemistry, one often talks about, e.g., sulfuric acid—and everyone knows what is meant—but mostly means the aqueous solution of sulfuric acid; or when an experiment is observed, observing means not only looking, but also smelling, feeling, and hearing. Pointing out these differences is important for pre-service chemistry teachers to be able to develop awareness themselves and to use Chemish more precisely in school.

We agree with Rollnick [80] (p. 577) as she states that (scientific) language is a key point in science teacher education as "(i) the appropriate use of language strategies in teaching science [. . .] need to be modeled by teacher educators" and (ii) language awareness of pre-service science teachers is very important. However, we do not see this as a topic solely of chemistry education courses. (Critical) language awareness must also be developed on the part of the chemistry teacher educators as a whole as they act as models for language usage. Not having university teacher educators actively focusing and reflecting on language usage—especially on Chemish—in general chemistry and other courses, pre-service chemistry teachers do not learn to differentiate between scientific language and laboratory jargon as commonly used in university chemistry courses. Another point that complicates matters is that pre-service science teachers are likely to adopt the methods of teaching scientific vocabulary from their own school experience [56,81]. If there is no initial teacher training on teaching and learning Chemish, the pre-service teachers are even likely to adopt these traditional methods in their teaching [82]. To counteract the adoption of traditional methods, in addition to addressing Chemish in university teacher training in general chemistry and chemistry education courses, methods should also be provided that the pre-service chemistry teachers must try out in school during their university teacher training program and thus incorporate them directly into their repertoire of methods and thus have applicable knowledge when it comes to the teaching and learning of Chemish. As the research of Carrier and Grifenhagen [81] shows, the results of explicit training on vocabulary support are promising. However, it is important to ensure that the interventions are not exclusively at the vocabulary level, but also the meta-level. When explicitly talking about Chemish and how it is used to conduct meaning, students can also develop (critical) language awareness and metalinguistic awareness. The question arises whether fostering the (critical) language and metalinguistic awareness of students sensitizes them for (scientific) language usage in other school subjects. Thus, there is no question that Pedagogical Scientific Language Knowledge must be developed by teachers of other scientific subjects as well. In addition to the (critical) language and metalinguistic awareness regarding Chemish of teacher educators and pre-service teachers, the better connection of content and didactics to promote the relevance of the CK and at the same time the PCK, and the school practice accompanying the university teacher training program, another point can be the exemplary elaboration of particular Chemish terms and related concepts. For example, pre-service chemistry teachers might think about a particular Chemish term, what the students' preconceptions of it might be, what other terms need to be known (or can be disregarded), what knowledge the students will later acquire about the concept according to the curriculum and thus make the introduction of the particular term connectable throughout the spiral curriculum, what misconceptions about the concept might arise based on improper language usage, etc. Another point to note is that different seminar sessions need to be well connected and not stand alone so that the pre-service chemistry teachers can get a big picture of what it means to teach Chemish. One possibility would be to work in projects, e.g., to exemplary work on contents of the curriculum, to acquire the PCK in general, but at the same time to check the contents for Chemish and therefore develop and apply PSLK. This approach could also be applied to other scientific disciplines that have a very complex scientific language that requires a high degree of accuracy in its use.

Although in recent years university teacher education has changed and seminars on teaching language are offered, majority of the seminars focus on language sensitiveness considering second language students' learning. Furthermore, as this study shows that the focus of university teacher education needs to be more on PSLK, more research is needed focusing on in-service teachers' PSLK to see how actual chemistry teachers deal with the challenge of teaching and learning Chemish as it remains a rather theoretical construct. This would help to make the concept of PSLK comprehensible in the first place and to see from which knowledge areas the PSLK is finally built up in practice. This could help to prepare pre-service chemistry teachers even better for teaching and learning Chemish since the training can focus directly on the knowledge that is helpful for teachers when teaching Chemish.

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