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The Refined Consensus Model of Pedagogical Content Knowledge (PCK): Detecting Filters between the Realms of PCK

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Abstract: In this article, we analyse potential filters that moderate the transformation process between the realms of PCK defined in the refined consensus model of pedagogical content knowledge. We tested 58 preservice biology teachers in a 15-week one-group pretest/post-test design. To identify filters between collective PCK (cPCK) and personal PCK (pPCK), we set up moderation models with pretest pPCK as an independent variable, post-test pPCK as a dependent variable, and motivational orientations or professional values as moderator variables. To identify filters between pPCK and enacted PCK (ePCK), we set up moderation models with post-test pPCK as an independent variable, ePCK as a dependent variable, and noticing or knowledge-based reasoning as moderator variables. We did this specifically with a focus on language in biology education. We found that only the variable knowledge-based reasoning had a role as a filter. It moderates the transformation process between pPCK and ePCK (moderation analysis: $F(3,19) = 10.40$, $p < 0.001$, predicting 25.72% of the variance). In future studies, other filters should be identified.

Keywords: refined consensus model (RCM); pedagogical content knowledge (PCK); language-sensitive biology instruction; biology education

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1. Introduction

The refined consensus model (RCM) of pedagogical content knowledge [1] is on everyone's lips in the science-education community: research groups worldwide discuss it. The RCM was developed by more than 20 international researchers in science-teacher education based on the so-called 2012 consensus model [1,2]. On the one hand, the RCM is extremely exciting, as it integrates the empirical results and theoretical models of different research groups from all over the world; on the other hand, it raises several questions, as science teachers' pedagogical content knowledge (PCK) [3] is thought to exist in three distinct realms [1]. These questions might be: "How can these realms of PCK be measured?", or "How are these realms transformed into one another?" Following Carlson and Daehler's [1] (p. 92) summons, "Now, it is time to test the model", we propose test instruments to measure the different realms of PCK, and to try to answer the question of how the realms of PCK can be transformed. As language proficiency is one of the greater impact factors on the performances of students [4], we follow these questions with a focus on language proficiency in linguistically heterogeneous learning groups in biology instruction.

1.1. The Refined Consensus Model of PCK

Shulman [3] defined teachers' PCK as the knowledge of how to impart knowledge to students, of the useful representations to accomplish this, and students' preconceptions and how to deal with them. Since then, science-education research has tried to describe this construct more precisely by differentiating between the realms of PCK, as Carlson and Daehler [1] suggested in the *refined consensus model (RCM) of PCK*. They identified three distinct realms of PCK: collective PCK (cPCK) (shared and published PCK), personal PCK (pPCK) (a teacher's unique internalised PCK), and enacted PCK (ePCK) (the PCK expressed in a concrete teaching situation).

1.1.1. Three Realms of PCK

Collective PCK (cPCK). The PCK that is commonly shared within the professional community and that is published in books is described as cPCK [1]. Professional knowledge bases, such as content knowledge and pedagogical knowledge [3,5], as well as documented teaching experience, contribute to cPCK. Carlson and Daehler [1] describe cPCK as a continuum: from broad superior discipline-specific PCK to more specialised topic-specific PCK to concrete concept-specific PCK. Discipline-specific PCK is the knowledge about fostering students' understanding of the Nature of Science (e.g., the knowledge of and why it is necessary to conduct a model critique). Within a discipline, PCK can be described more specifically for each topic as topic-specific PCK, which is the knowledge about students' preconceptions about, for example, the circulatory system, such as "there is only one blood stream in the human body", and how to deal with them. Concept-specific PCK is the concrete exemplary knowledge within each topic about using core concepts to foster students' conceptual learning (e.g., the concept of the structure and function to enable students to answer questions such as "How is the hedgehog adapted to its habitat?").

Personal PCK (pPCK). An individual teacher's internalised form of PCK, the knowledge they will use in class, is described as pPCK [1]. Teachers take up cPCK by consulting literature, joining teacher training sessions, or discussions with colleagues, and they construct their individual pPCK, which forms their knowledge base, which is to be retrieved in teaching situations. The articulation, empirical evaluation, and publication of one person's pPCK (e.g., in research journals or books) transform the pPCK of single persons into cPCK.

Enacted PCK (ePCK). The form of PCK that a teacher applies individually in any teaching situation is described as ePCK by Carlson and Daehler [1], who define it as a subset of pPCK, as teachers use their pPCK when it becomes visible in the chosen teaching strategies, lesson structure, tasks that the students have to work out, models used, and when dealing with student errors. Because ePCK is considered to exist only in action and in a definitive teaching episode, it is impossible to recall the same ePCK outside that situation, and thus, it is more difficult to describe than the other realms. Alonzo et al. [6] describe ePCK in the form of a **p**lan–**t**each–**r**eflect cycle, following the three steps of teaching: teachers generate $ePCK_P$ **p**lanning a lesson; they generate $ePCK_T$ in the **t**eaching situation; they generate $ePCK_R$ **r**eflecting after the lesson [6]. Each piece of ePCK that is generated in the teaching situation contributes to the increase in or modification of the teachers' pPCK [6].

The RCM is visualised as a concentric circle, with the plan–teach–reflect cycle of ePCK in the centre, embedded in teacher's pPCK, and surrounded by cPCK as an outer circle (Figure 1). This visualisation shows the close linkage between the realms of PCK and their mutual influence. Carlson and Daehler [1] also emphasise that the continuum of discipline-, topic-, and concept-specific PCK that is described for cPCK applies to all realms of PCK. Considering the realms of PCK as a continuum implies that, horizontally, PCK ranges from a broader angle of view (discipline-specific) to a narrower angle of view (concept-specific). Vertically, the knowledge level of PCK, and especially pPCK and ePCK, can vary from the basic level to the expert level.

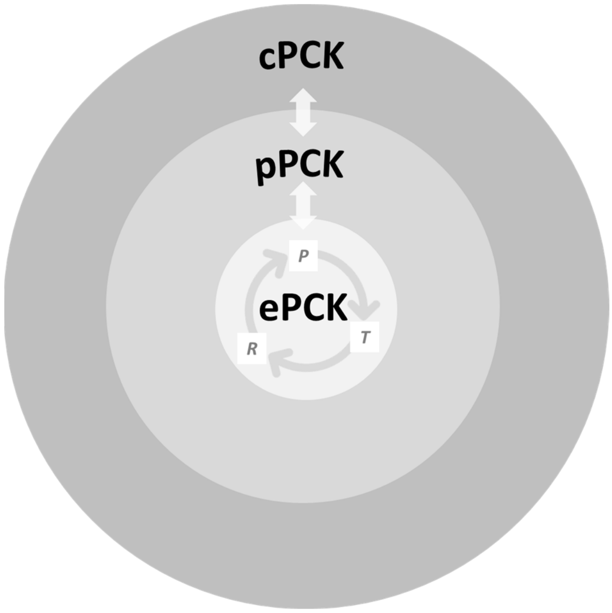

Figure 1. The refined consensus model of PCK based on Carlson and Daehler [1]. **P** represents the step **p**lan, **T** the step **t**each, and **R** the step **r**eflect in the plan-teach-reflect cycle of ePCK [7].

1.1.2. Assumed Transformation Processes between the Realms of PCK

To answer the question of how the three realms of PCK are transformed into one another (Figure 2), Carlson and Daehler [1] assume different filter and/or amplifier mechanisms that moderate the transformation processes between the described realms of PCK. In the following sections, we will only name them as filters, and we describe them in more detail.

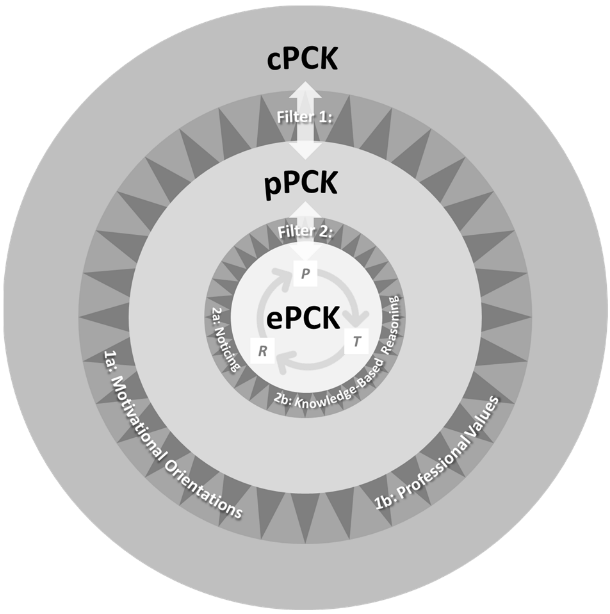

Figure 2. The RCM with proposed filters between cPCK and pPCK (Filter 1), and between pPCK and ePCK (Filter 2).

Motivational Orientations and Professional Values as Filter 1

For the transformation process from cPCK to pPCK and vice versa, Carlson and Daehler [1] suggest the so-called learning context as a filter. This learning context is described as everything that influences learning processes, such as national educational policies, the equipment of schools and classrooms, and the individual characteristics of the learning group, such as age and language proficiency. Furthermore, they assume affective factors, such as teachers' attitudes and beliefs and previous classroom experience, to be filters. In the original representation of the RCM, the learning context is situated as a further circle between cPCK and pPCK [1] (p. 83) to illustrate the partition between the individual teacher, with his/her individual pPCK, and the science-education community, with its common cPCK.

Carlson and Daehler's [1] learning context is a huge construct with a myriad of interplaying factors. Because this construct could have an impact on teachers' attitudes and beliefs, and Carlson and Daehler [1] named them explicitly, we suggest focusing on these as filters between cPCK and pPCK (Figure 2). We will use the terms *motivational orientations* and *professional values* [6] to describe them in more detail.

Teachers have beliefs about their own abilities and their role as teachers [7], they feel enthusiasm for their profession and their subject [8], and they have and develop professional ethics, including responsibility and solicitude [9]. Teachers' ability beliefs and enthusiasm especially influence their achievement choices [5,10].

Baumert and Kunter [5] use the term *motivational orientations* to describe teachers' ability beliefs and enthusiasm, which dictate the quality, intensity, and duration of a teacher's behaviour [8,11]. Constructs that belong to the motivational orientations are—according to Wigfield and Eccles [10]—teachers' ability beliefs, perceptions of task demands, utility values, intrinsic values, expectations of success, and personal costs. We suggest using these constructs to describe the first part of Filter 1, between cPCK and pPCK, as these constructs influence teachers' decisions before, in, and after classroom situations.

It has not yet been clarified how and by how much a teacher's personal value commitments and professional ethos influence their professional behaviour, but they are thought to do so [12]. Baumert and Kunter [5] use the term *professional values* to describe the attitude that a teacher has towards his/her students, with the teacher's individual characteristics, responsibility for students' learning, and perception of biases and fairness [9,12]. Furthermore, a teacher's affectations for guiding principles in life [13], including a critical look at one's own prejudices, power, and discriminating behaviour [14–16], can be counted as professional values.

The nature of the values that a person develops during their life depends on his/her socialisation, culture, individual needs, and experiences (e.g., [17,18]). Because values in general, and professional values as well, are considered to be decisive factors of a person's perception of his/her environment, (professional) goals, attitude towards other people or issues in general, and behaviour [17], they should play a further decisive role for a teacher's (unaware) decisions on which parts of cPCK they will integrate into their pPCK, and vice versa. Therefore, professional values are also considered to be a filter between cPCK and pPCK.

Noticing and Knowledge-Based Reasoning as Filter 2

For the transformation process from pPCK to ePCK, and vice versa, Carlson and Daehler [1] suggest the teacher's pedagogical reasoning as a filter. Because a teacher's pPCK base is enormous, they have to decide which parts of their pPCK are useful and necessary in the unique classroom situation on the basis of experience and advice. The original representation of the RCM does not (yet) include this filter as a further circle between pPCK and ePCK.

We suggest the use of the model of professional vision [19–22] to describe Carlson and Daehler's [1] pedagogical reasoning, and to include a further filter into the representation of the RCM (Figure 2). A teacher's professional vision is characterised by the skills of noticing and knowledge-based reasoning [21]. *Noticing* is defined as a teacher's ability to direct his/her own attention to events in the class that are relevant for teaching and learning [22,23]. *Knowledge-based reasoning* is defined as a teacher's ability to rate those events on the basis of his/her professional knowledge [23,24]. Teaching situations are extremely complex; innumerable things happen during a lesson, which is why a teacher has to be able to assess each incident within seconds, and to act in an appropriate way. Knowledge-based reasoning is usually classified according to three distinct but highly interrelated aspects: description, explanation, and prediction [23,25]. The first step to reasoning about a classroom event is description, which refers to presenting the event precisely, without ranking it. Next, the described event has to be related to the teacher's professional knowledge so that he/she can give an explanation in a way in which the event is important for the students' learning. In the third step, a prediction of potential consequences can be made [23]. Proposing alternative instructional strategies in class can be described as a further aspect of knowledge-based reasoning [26,27].

Noticing and knowledge-based reasoning describe the constant processes that a teacher is confronted with in each teaching situation, and they differ from learning group to learning group, and from lesson to lesson. Therefore, these could be the determining factors in the transformation process from pPCK to ePCK.

If we take a closer look at ePCK, which is considered to exist in the plan–teach–reflect cycle [6], then we can relate each part to pPCK by considering the moderators noticing and knowledge-based reasoning. In the planning process, teachers try to "pre-notice" potentially relevant classroom events, such as students' questions or difficulties in understanding. Then, they think about consequences, strategies to prevent or deal with them, and alternative instructional strategies, which are knowledge-based reasoning. In the teaching situation, they notice events and use knowledge-based reasoning, as described above, within seconds. Reflecting after the lesson, they remember the noticed events, and thus mentally "describe" them and reason about them, having much more time, often with a focus on pros and cons, as well as alternative instructional strategies. Each teaching experience, going through the plan–teach–reflect cycle of ePCK, contributes to the development of a teacher's pPCK [1]. We assume that the more knowledge-based reasoning is performed, the more pPCK should be developed or modified; therefore, noticing and knowledge-based reasoning are considered to be filters between ePCK and pPCK in both directions.

We will analyse the filters between the realms of PCK with a focus on language proficiency in linguistically heterogeneous learning groups. Therefore, we will next introduce the importance of language in science education.

1.2. Language in Science Education

The findings of Prediger et al. [4] support that students' language proficiency, among all other social- and language-background factors, has the greatest impact on students' achievement in class. Academic literacy in science can be described as participation in science discourse, involving conceptual understanding (described for mathematics by [28]). This discourse includes, besides text comprehension and production, the use of sketches or tables, and the ability to switch between language registers [28]. Registers describe areas of language use that are characterised by specific terms and grammatical structures [29]. For science education, the science register, academic register, and everyday register are considered to be relevant [28,30,31]. The language of biology is characterised by specific technical terms and forms of representation [32], as it is impossible for students to experience abstract concepts in science directly [33]. Biological technical terms often cause problems for students' understanding because they are used in the science register as well as in the everyday register—with different meanings [34,35]. In students' everyday lives (and language), they experience a division in mathematical meaning: they have one whole apple, they divide it, and they have two halves of an apple. In biology, division means the contrary: there is one cell, and after cell division, there are two whole identical cells. Further examples would be "delivery" (the distribution of goods vs. childbirth), "to experiment" (to test something vs. a scientific way of working), or "anvil" (a blacksmith's tool vs. a part of the ossicles). To be able to use and create biology-specific forms of representation [32,36], students have to know how to write a scientific protocol [37], which differs significantly from a protocol in language lessons, and to describe, interpret, and construct a diagram [38]. The description and interpretation, especially, require academic- and science-language proficiency: one has to identify and name the independent and dependent variables to describe the curve progression by using terms such as "increases sharply", "flattens lightly", and "stagnates", or grammatical structures such as "the more ... the more ...". These rare examples illustrate why a biology teacher has to be aware of linguistic hurdles, and to know about appropriate teaching strategies.

Insufficient language proficiency can also lead to exclusion from learning issues, as well as from social discourse [16,39]. A very recent example follows: The media were full of COVID-19 pandemic-related reports. There were illustrations of the SARS-CoV-2 virus, diagrams showing the seven-day incidences in different countries and the numbers of vaccinated and nonvaccinated patients treated in intensive care units, and discussions about mRNA versus inactivated vaccines. "When one knows the language of discourse, she can interact and negotiate within the arena of play to her advantage" [40] (p. 320). Only if one has the biological knowledge to interpret this news and the forms of representation, which requires adequate scientific-language proficiency, is one able to follow the recent discourse. On the assumption that participation in social discourse is the highest aim of education, science classes are requested to enhance students' language proficiency on the basis of their pre-existing everyday- and academic-language skills [31,41]. Unfortunately, science teachers' higher education usually does not (yet) aim at fostering these skills [42].

1.3. The RCM and the Example of Language in Biology Education

By using the example of language in biology education, the content dimension of all three realms of PCK would relate to a teacher's knowledge about how to foster academic-language use in particular contexts [43]: the "*knowledge of scientific language related to teaching and learning [science]*, focusing on different scientific topics and contexts" [42] (p. 181), which is the construct that we assume to be the most relevant domain of professional knowledge to foster students' language proficiency in biology class.

We have suggested motivational orientations and professional values as filters for the transformation process between cPCK and pPCK. A teacher's *professional values regarding multilingualism and responsibility for students' language development* [14,16,36,39,44] are considered to be particularly relevant in the context of language in biology education: Does the teacher feel responsibility for students' language development? Does the teacher regard multilingualism as a deficit or a resource? How important is it for the teacher to impart scientific language? Is the teacher aware of language as an instrument of power? Because self-efficacy beliefs and enthusiasm [5] influence a teacher's achievement choices, as well as their performance, effort, and persistence [10], *motivational orientations to implement language-sensitive biology instruction* [10,45,46] should play a decisive role in the transformation from cPCK to pPCK: What does the teacher expect from implementing language-sensitive biology lessons? Does the teacher feel able to do that? Is there teacher training or didactic materials supporting the teacher? How does the teacher judge the benefit of language-sensitive biology lessons for his/her students? Is the teacher interested in the meaning of language in biology education? How much time does the teacher have to invest to develop language-sensitive lessons?

Teachers' noticing and knowledge-based reasoning are considered to be further filters for the transformation process between pPCK and ePCK. Teachers (pre-) *notice relevant events regarding students' language proficiency*: when they plan a lesson, they have to think about the subject-related language that the topic requires, possible linguistic barriers, and scaffolding strategies. In the teaching situation, they have to be sensitive to linguistic barriers, and to their own precision in describing biological issues. During the whole plan–teach–reflect cycle of ePCK, they have to think about consequences, and strategies to prevent or deal with them, as well as alternative instructional strategies, and thus they employ *knowledge-based reasoning about relevant events regarding students' language proficiency*: How can I obviate embarrassing situations for my students but make them contribute in verbal and written forms to the lesson at the same time? Which scaffolding strategies would be useful? Would it be useful to allow my students to use their first language during the group work? Providing audio files in addition to the text worked quite well for my other class, would that be an opportunity for this class, too? I remember the situation eight weeks ago, when my class struggled with the description of the diagram. We should repeat that by another example, and I could provide scaffolding, such as "the independent variable is ..., the dependent variable is ...".

2. Hypotheses

Within this study, we analyse two presumptive filters within the RCM that might influence the transformation between: (1) cPCK and pPCK, and (2) pPCK and ePCK, with a focus on language proficiency (Figure 3).

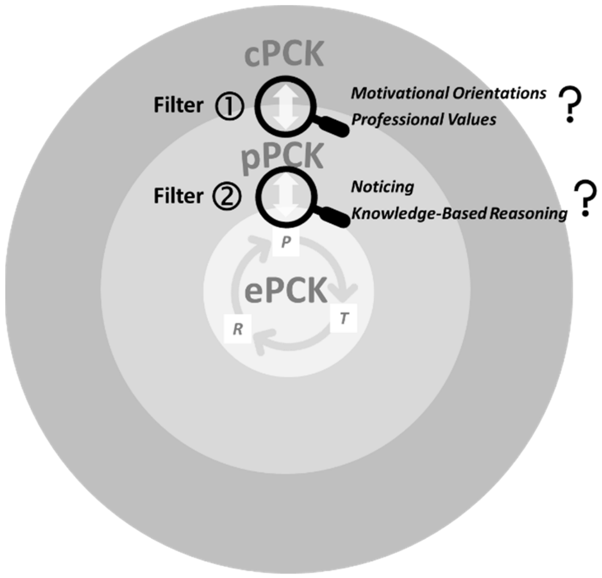

Figure 3. Hypothesised filters between cPCK and pPCK (Filter 1), and between pPCK and ePCK (Filter 2).

2.1. Filter 1 between cPCK and pPCK

H1a. *Motivational orientations to implement language-sensitive biology instruction moderate the transformation process from cPCK to pPCK for Filter 1a.*

H1b. *Professional values regarding multilingualism and responsibility for students' language development moderate the transformation process from cPCK to pPCK for Filter 1b.*

2.2. Filter 2 between pPCK and ePCK

H2a. *The noticing of relevant events regarding students' language proficiency moderates the transformation process from pPCK to ePCK for Filter 2a.*

H2b. *Knowledge-based reasoning about relevant events regarding students' language proficiency moderates the transformation process from pPCK to ePCK for Filter 2b.*

3. Methods

3.1. Setting

We tested our hypotheses in an obligatory advanced seminar for preservice secondary biology teachers. This seminar focuses on biology-specific PCK, including language-sensitive aspects. There is a special focus on theory-based lesson planning. Among other things, participants are confronted with cPCK, and they have to use their acquired pPCK for theory-based lesson planning. The seminar's duration is 15 weeks, for 90 min each week. Three ECTS credits (European Credit Transfer and Accumulation System; one ECTS credit is equivalent to 25–30 working hours) can be acquired.

3.2. Sample

The sample of the study consisted of 58 preservice biology teachers for secondary schools (37 female, 21 male), all of them with German as a first language, and 13 of them who are bilingual. On average, they were in their 7th semester (M = 6.98; SD = 0.58).

3.3. Design and Procedure

The study was a one-group pretest/post-test design (Figure 4). At the beginning of the seminar, the participants' $pPCK_{pre}$ (pretest), motivational orientations, and professional values were measured. At the end of the seminar, the participants $pPCK_{post}$ (post-test), noticing, knowledge-based reasoning, and ePCK were tested. The pPCK tests at the beginning and end of the seminar were the same.

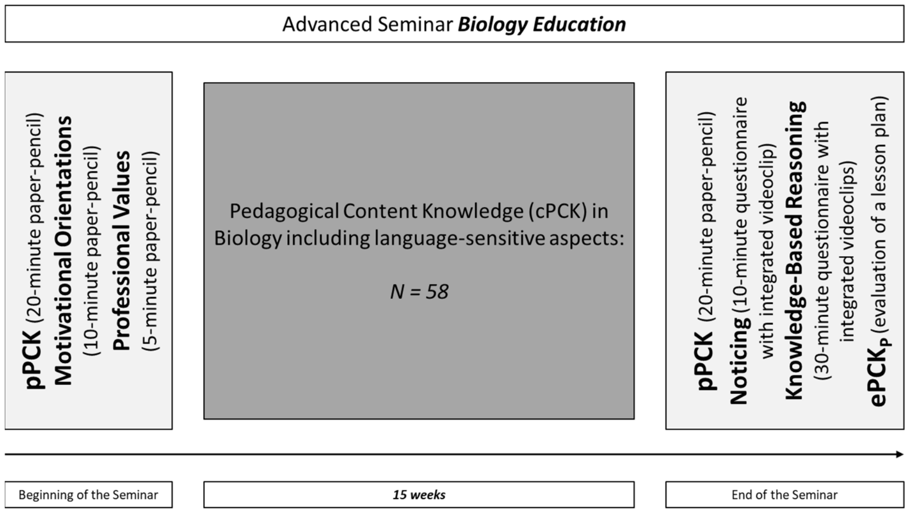

Figure 4. Research design and procedure.

Content of the Seminar. The focus of the seminar was to lecture cPCK, integrate it into the participants' pPCK, and transform it into the participants' ePCK. The participants obtained theoretical cPCK instruction from the lecturer, and practical examples of how to transfer the knowledge into classroom practice: each week, this was focussed on another aspect of cPCK (e.g., appropriate language use and scaffolding, elaborate model use, dealing with students' preconceptions, or the embedding of scientific-inquiry methods). Therefore, the lecturer gave a short summary of the current research in the field and its implications for student learning (e.g., knowledge about the relevant language registers, linguistic hurdles in biology lessons, and appropriate scaffolding strategies [16,31,35]). Examples of students' answers to biology tasks were presented, and helpful strategies to prevent and solve linguistic struggles were discussed. In the next step, the preservice teachers were requested to use that presented cPCK knowledge to plan a lesson on their own, to present the lesson to the other participants, and to reflect on these lessons within the seminar group. Therefore, a tabular form of the lesson plan had to be used, which provided, for example, an extra column to write down the necessary linguistic tools that the students would have to understand and use to be able to follow the lesson content. In this way, they should integrate the lectured cPCK into their own pPCK and transfer it into ePCK.

3.4. Test Instruments

The pPCK, motivational orientations, and professional values were measured by paper-and-pencil questionnaires; the noticing and knowledge-based reasoning were measured with questionnaires that included videos showing real teaching situations that had to be rated; the ePCK was measured by evaluating the preservice teachers' lesson plans. All the test instruments showed acceptable values for homogeneity and objectivity (Table 1). The values for the reliability were computed by using the Rasch theory [47], which enabled the conversion of the nonlinear raw scores from our measurements to linear person-ability scores that could be used for data analysis. The person-ability scores were converted to a range from 0 to 100 [48]. Rasch analysis evaluates data by fitting via item infit and outfit MNSQs (mean squares; [49]), and statements on the reliability via the item reliability and person reliability. All data met the desired requirements (Table 1; [49–51]). We used the programme Winsteps [52] for the Rasch scaling.

Table 1. Summary of test instruments.

Variable	Number of Items	All Item Infit MNSQ	All Item Outfit MNSQ	Item Reliability	Person Reliability	ICC (Unjust)
pPCK	$N = 9$	<1.4	<1.4	0.99	0.75	ICC (159,159) = 0.97, $p < 0.001$
Motivational Orientations	$N = 34$	<1.4	<1.4	0.98	0.88	-
Professional Values	$N = 27$	<1.3	<1.3	0.98	0.76	-
Noticing	$N = 12$	<1.3	<1.3	0.92	0.63	-
Knowledge-Based Reasoning	$N = 46$	<1.3	<1.3	0.91	0.44	-
ePCK	$N = 8$	<1.5	<1.5	0.97	0.86	ICC (534,534) = 0.98, $p < 0.001$

In the following section, we will describe each scale in more detail.

pPCK. We measured pPCK_{pre} and pPCK_{post} with a focus on students' language proficiency in biology class by an open-ended paper-and-pencil test with nine items, which took the preservice teachers 20 min [53]. The test was based on a validated test of Jüttner et al. [54]. They constructed the test instrument in four steps: first, they conceptualised a variable utilising theory; second, they selected topics for the PCK instrument; third, they constructed a blueprint; four, they constructed items based on Schmelzing et al. [55]. Afterwards, the test was validated using think-aloud interviews for the content validity, and group comparisons for the construct validity [56,57]. We decided to use and adapt this test instrument for our content area of PCK following the recommendations of Reeves and Marbach-Ad [58]: we defined the content area of language in biology education based on a literature review (e.g., [29–32,35,42]), and by defining learning objectives for preservice biology teachers [59], and we constructed theory-based items according to those of Jüttner et al. [54]. This content validity was strengthened by submitting the items to a small group of in-service biology teachers and biology-education researchers. They were requested to answer the test items in a first step, and to give their feedback in a second step: Did they know what they were supposed to do? Would they recommend other wording? Did they feel we missed anything important to cover the topic of academic and science language? Furthermore, the construct validity of the test was evaluated by using the Wright map of the Rasch analysis [60,61], which showed an even distribution of the item difficulties. Thereby, items that were easier to agree with were located at the lower end of the Wright map (e.g., "Define the term 'everyday language' and give an example."), and items that were more difficult to agree with were located at the upper end of the Wright map (e.g., "Highlight characteristics of academic language in the following text."). The test was based on the Rasch partial credit model (PCM) [52,62], which allows for a consideration of multiple item levels. The test included questions on the classroom-relevant language registers [29,31], requests to notice and name examples for the academic and science registers in a schoolbook's text, requests to lighten the linguistic load of a biology task in a well-founded way, and one item asking the participants to name and explain as many terms as possible with different meanings in the everyday and science registers [34,35]. For objectivity, 10% of the sample was double coded by two independent researchers, who showed a high agreement (ICC (159,159) = 0.97, $p < 0.001$). After the application of the Rasch PCM, the scale showed acceptable values for homogeneity (item reliability = 0.99; person reliability = 0.75), and all items showed good fit values (Table 1).

Motivational Orientations. We measured motivational orientations to implement language-sensitive biology instruction by paper-and-pencil questionnaire with 34 items on a five-point Likert scale (ranging from strongly disagree to strongly agree), which took the preservice teachers ten minutes. It is based on the expectancy-value theory of achievement motivation [10,45], adapted to language-sensitive biology instruction from an existing instrument [46], whereby only the term "concept-orientated" was replaced by the term "language-sensitive". It consisted of six subscales: expectation of success (seven items; e.g., "If I offer language-sensitive classes, I will get more recognition from colleagues."); ability beliefs (five items; e.g., "I am able to develop language-sensitive tasks."); perception of task demands (six items; e.g., "I feel well prepared to teach language-sensitive lessons."); utility value (seven items; e.g., "Students will make more contributions in language-sensitive lessons than in other ones."); intrinsic value (five items; e.g., "It is interesting for me to teach language-sensitive lessons."); personal cost (four items; e.g., "To teach language-sensitive lessons, I have to invest much time into the development of teaching materials."). For the construct validity, we evaluated the Wright map [60,61], which showed an even distribution of the item difficulties. Thereby, items that were easier to agree with were located at the lower end of the Wright map (e.g., "If I offer language-sensitive biology instruction, I better fulfil my duties as a teacher."), and items that were more difficult to agree with were located at the upper end of the Wright map (e.g., "To be able to offer language-sensitive biology instruction, I need much time to develop teaching materials."). The Rasch PCM was used to analyse the questionnaire, and acceptable values for homogeneity (item reliability = 0.98; person reliability = 0.88) and good item-fit values were found (Table 1).

Professional values. Professional values regarding multilingualism and responsibility for students' language development were measured on a four-point Likert scale (ranging from strongly disagree to strongly agree) paper-and-pencil questionnaire with 27 items, which took the preservice teachers five minutes. Because there were no existing instruments at the time, this instrument was developed within the context of this study. Within the development process, we first interviewed former freshly graduated students with a non-German native language about their experiences at school, and especially in biology class and with biology teachers. Secondly, we consulted the literature on migration- and language-related discrimination (e.g., [14,39,63]). On this basis, we defined 4 subscales and developed 27 items (Figure 5): attitude towards their own responsibility for language education in their classes (7 items; [16]); attitude towards multilingualism among their students (6 items; [14,16]); attitude towards the teaching of science language as a goal of biology lessons (5 items; [36]); awareness of language as an instrument of power (9 items; [14,16]). To improve the content validity, thirdly, we submitted the items to a group of in-service biology teachers and asked them to write down their thoughts [58] (e.g., if they would recommend other wording, or if we missed anything important to cover the topic multilingualism and responsibility for students' language development). For the construct validity, we used the Wright map after Rasch analysis [60,61], which showed an even distribution of the item difficulties. Therefore, items that were easier to agree with were located at the lower end of the Wright map (e.g., "It is a goal of biology lessons to understand biology-specific science language."), and items that were more difficult to agree with were located at the upper end of the Wright map (e.g., "Students are also allowed to use their non-German first language in my classes when working in a group.").

	strongly agree	agree	disagree	strongly disagree
Multilingual students have a special resource that can only benefit them in my classes.	☐	☐	☐	☐
Students are also allowed to use their non-German first language in my classes when working in a group.	☐	☐	☐	☐
Only German is spoken in my classes. (-)	☐	☐	☐	☐
I make use of the multilingualism of my students in my classes and actively include their linguistic resources.	☐	☐	☐	☐
I feel uncomfortable when students use their first (non-German) language in my presence. (-)	☐	☐	☐	☐

Figure 5. Item examples from the professional-values test.

Data were analysed by the Rasch PCM and showed acceptable values for homogeneity (item reliability = 0.98; person reliability = 0.76), as well as good item-fit values (Table 1).

ePCK. We measured ePCK with a focus on students' lesson planning, specialised on language proficiency in biology class, by collecting and evaluating preservice teachers' written lesson plans. The lesson plans were to be in tabular form, and they were to include learning objectives and a detailed presentation of the lesson, including all necessary teaching materials. The evaluation was performed by using a rating manual that includes eight items [64,65], which was developed following the recommendations of Reeves and Marbach-Ad [58]: the content area of language in biology education was defined based on a literature review (e.g., [16,66–71]), followed by defining learning objectives for preservice biology teachers [59], and the construction of theory-based items. For the construct validity, the Wright map of the Rasch analysis [60,61] was evaluated, which showed an even distribution of the item difficulties. Therefore, items that were easier to agree with were located at the lower end of the Wright map (e.g., "All new technical terms are explained, repeated and written down."), and items that were more difficult to agree with were located at the upper end of the Wright map (e.g., "There are necessary and useful linguistic tools for all phases of the lesson."). The rating manual included items relating to appropriate linguistic tools, an appropriate use of language and technical terms, and appropriate linguistic scaffolding strategies [16,53,66]. For objectivity, 10% of the lesson plans were double coded by two independent researchers, who had a high agreement (ICC (534,534) = 0.98, $p < 0.001$). Applying the Rasch PCM led to acceptable values for homogeneity (item reliability = 0.97; person reliability = 0.86), and good item-fit statistics (Table 1).

Noticing. We measured preservice teachers' noticing of classroom events relevant for students' language proficiency by using a test with 12 dichotomous items, which took the preservice teachers ten minutes. The test instrument was developed following the recommendations of Reeves and Marbach-Ad [58]: the content area of language in biology education was defined based on a literature review (e.g., [16,67–71]), followed by defining learning objectives for preservice biology teachers [59], and the construction of theory-based items. For the construct validity, the Wright map of the Rasch analysis [60,61] was evaluated, which showed an even distribution of the item difficulties. Therefore, items that were easier to agree with were located at the lower end of the Wright map (e.g., the technical term "vesicle" had to be noticed), and items that were more difficult to agree with were located at the upper end of the Wright map (e.g., a student's wrong answer had to be noticed). The test included a 10 min videoclip presenting 12 classroom events relevant for students' language proficiency [16,35,67], which had to be recognised by the preservice teachers. Recognising the event would mean that the item was coded with "applies", and missing the event would mean that the item was coded with "does not apply". The videoclip and preservice teachers' answers were embedded into a web-based platform. The resulting data were analysed by the Rasch PCM, and they showed acceptable values for homogeneity (item reliability = 0.92; person reliability = 0.63), and good item-fit values (Table 1).

Knowledge-based reasoning. We measured preservice teachers' knowledge-based reasoning about classroom events relevant for students' language proficiency by using a multiple-choice test with 46 items, which took the preservice teachers 30 min. We developed this test instrument following the recommendations of Reeves and Marbach-Ad [58]: we defined the content area of language in biology education based on a literature review (e.g., [16,67–71]), and by defining learning objectives for preservice biology teachers [59], and we constructed theory-based items. This content validity was strengthened by submitting the items to a small group of in-service biology teachers and biology-education researchers who were requested to answer the test items in a first step, and to give their feedback in a second step: Did they know what they were supposed to do? Would they recommend other wording? Did they feel we missed anything important to cover the topic of academic and science language? Furthermore, the construct validity of the test was evaluated by using the Wright map of the Rasch analysis [60,61], which showed an even distribution of the item difficulties. Therefore, items that were easier to agree with were located at the lower end of the Wright map (e.g., "The teacher writes down each new technical term on the black board."), and items that were more difficult to agree with were located at the upper end of the Wright map (e.g., "The teachers' reaction to a students' statement is pejorative. Explain what effects this can have on students' learning success. Refer to didactic and/or pedagogical theories." The test included the subscale description, explanation, and alternative instructional strategies. For this, seven one–three-minute videoclips presenting classroom events relevant for students' language proficiency had to be rated on a four-point Likert scale (ranging from strongly disagree to strongly agree). The scale included items about the use of technical terms [68], dealing with one's own language [72], promoting students' active language use [16], respectful interaction [69], and visualisation and cross-linking [70]. The videoclips and multiple-choice items were entered into a web-based platform. The scale showed acceptable values for homogeneity (item reliability = 0.91; person reliability = 0.44), and good item-fit values after the Rasch PCM was generated (Table 1).

3.5. Data Analysis

3.5.1. Descriptive Analyses

Mean values and standard deviations of all the resulting person-ability scores were used (Table 2). We calculated Pearson correlations between preservice teachers' motivational orientations and professional values, and between their noticing and knowledge-based reasoning. A paired *t*-test was calculated to check the difference between the preservice teachers' $pPCK_{pre}$ and $pPCK_{post}$.

Table 2. Summary of mean scores and all intracorrelations.

	Mean of Person-Ability Score	SD	Min	Max	1	2	3	4	5	6	7
1 *$pPCK_{pre}$*	44.73	7.32	28.59	66.31	1						
2 *Motivational Orientations*	48.57	0.63	47.14	49.78	-	1					
3 *Professional Values*	51.03	0.56	49.75	52.34	-	0.56 **	1				
4 *$pPCK_{post}$*	47.74	5.46	31.71	64.99	0.64 **	0.36 *	-	1			
5 *$ePCK_P$*	68.51	7.65	36.91	80.84	-	−0.29 *	-	−0.31 *	1		

Table 2. *Cont.*

	Mean of Person-Ability Score	SD	Min	Max	1	2	3	4	5	6	7
6 *Noticing*	50.39	1.57	46.57	54.78	-	-	-	-	-	1	
7 *Knowledge-Based Reasoning*	51.33	1.12	50.74	56.50	-	-	-	-	-	0.62 **	1

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

3.5.2. Moderation Analyses

Carlson and Daehler [1] refer to the hypothesised filters between the transformation processes between the realms of PCK as moderators. In statistical procedures, a moderator variable explains when there is a relation between the independent and dependent variables; the effect of a moderator variable is a form of interaction [73].

To test Hypothesis 1a, we calculated a moderation analysis with $pPCK_{pre}$ as an independent variable, $pPCK_{post}$ as a dependent variable, and motivational orientations as a moderator variable (Moderation Model 1a). To test Hypothesis 1b, we calculated a moderation analysis with $pPCK_{pre}$ as an independent variable, $pPCK_{post}$ as a dependent variable, and professional values as a moderator variable (Moderation Model 1b). To test Hypothesis 2a, we calculated a moderation analysis with $pPCK_{post}$ as an independent variable, ePCK as a dependent variable, and noticing as a moderator variable (Moderation Model 2a). To test Hypothesis 2b, we calculated a moderation analysis with $pPCK_{post}$ as an independent variable, ePCK as a dependent variable, and knowledge-based reasoning as a moderator variable (Moderation Model 2b; Table 3). All moderation analyses were conducted with PROCESS Makro in SPSS [73].

Table 3. Summary of moderation effects. The values R^2, F, p, 95% CI are for the effects of moderation. Gray shading indicates a statistically significant moderation effect.

Hypothesis	Independent Variable	Dependent Variable	Moderator Variable	R^2	F	p	95% CI
1a	$pPCK_{pre}$	$pPCK_{post}$	Motivational Orientations	1.27%	F(1,44) = 0.68	0.41	[−0.2222, 0.3591]
1b	$pPCK_{pre}$	$pPCK_{post}$	Professional Values	0.48%	F(1,44) = 0.17	0.68	[−0.3178, 0.4375]
2a	$pPCK_{post}$	ePCK	Noticing	5.56%	F(1,19) = 0.40	0.53	[−1.7464, 0.9203]
2b	$pPCK_{post}$	ePCK	Knowledge-Based Reasoning	12.95%	F(1,19) = 12.53	< 0.01	[−0.5034, 5.3879]

4. Results

Table 2 gives an overview over the descriptive results of the measured variables, and their intracorrelations used for further moderation calculations.

4.1. Correlations

We found strong correlations between the preservice teachers' motivational orientations and professional values (r = 0.56, $p < 0.001$; [74]), as well as between the preservice teachers' noticing and knowledge-based reasoning (r = 0.62, $p < 0.001$; Table 2).

4.2. Difference between $pPCK_{pre}$ and $pPCK_{post}$

There was a significant difference between the mean pPCK person-ability scores (M = 44.73, SD = 7.32; min = 28.59, max = 66.31) at the beginning of the semester (pretest), and preservice teachers' mean pPCK ability scores (M = 47.74, SD = 5.46; min = 31.71, max = 64.99) at the end of the semester (post-test); the paired *t*-test explored a small effect ($t(48) = -2.48$, $p < 0.01$, $d = 0.30$).

4.3. Filter 1 between cPCK and pPCK

We tested two different moderation models for the transformation from cPCK to pPCK.

In Model 1a, we analysed whether the interaction between $pPCK_{pre}$ and the preservice teachers' motivational orientations to implement language-sensitive biology instruction predicted their $pPCK_{post}$. The overall Model 1a was significant ($F(3,44) = 8.42$, $p < 0.001$), predicting 47.27% of the variance. This means that our two predictors were able to explain a major part of the variance in $pPCK_{post}$ [74]. An analysis showed that *motivational orientations to implement language-sensitive biology instruction* did not significantly moderate the change from preservice teachers' $pPCK_{pre}$ to $pPCK_{post}$ ($\Delta R^2 = 1.27\%$, $F(1,44) = 0.68$, $p = 0.41$) (Table 3). Whether motivational orientations to implement language-sensitive biology instruction would work as a filter between cPCK and pPCK was not supported by our data. Following recommendations by Hayes [73], the interaction term was dropped from Model 1a, which resulted in a new simple effects model: 1a *. This new Model 1a * revealed a significant relationship between the preservice teachers' $pPCK_{pre}$ and $pPCK_{post}$ ($\beta = 0.59$, $p < 0.001$), but no significant relationship between their motivational orientations and $pPCK_{post}$ ($\beta = 0.22$, $p = 0.05$).

Model 1b tested whether the interaction between $pPCK_{pre}$ and the preservice teachers' professional values regarding multilingualism and the responsibility for students' language development predicted their $pPCK_{post}$. The results showed that the overall Model 1b was significant ($F(3,44) = 5.50$, $p < 0.05$), predicting 42.92% of the variance. Therefore, changing the filter still results in an explanation of a large amount of variance in $pPCK_{post.}$ An analysis again showed that *professional values regarding multilingualism and responsibility for students' language development* did not significantly moderate the change from preservice teachers' $pPCK_{pre}$ to $pPCK_{post}$ ($R^2 = 0.48\%$, $F(1,44) = 0.17$, $p = 0.68$) (Table 3). Whether professional values regarding multilingualism and the responsibility for students' language development would work as a filter between cPCK and pPCK was not supported by our data. Following recommendations by Hayes [73], the interaction term was dropped from Model 1b, resulting in a new simple effects Model: 1b *. This new Model 1b * revealed a significant relationship between the preservice teachers' $pPCK_{pre}$ and $pPCK_{post}$ ($\beta = 0.63$, $p < 0.001$), but no significant relationship between their professional values and $pPCK_{post}$ ($\beta = 0{,}11$, $p = 0.34$).

4.4. Filter 2 between pPCK and ePCK

For the transformation from pPCK to ePCK, two further moderation models were calculated.

In Model 2a, we investigated whether the interaction between the preservice teachers' $pPCK_{post}$ and their noticing of relevant events regarding students' language proficiency predicted their ePCK. This Model 2a was not significant ($F(3,19) = 0.41$, $p = 0.75$), meaning that these two predictors were unsuitable for explaining the variance in ePCK. An analysis showed that the *noticing of relevant events regarding students' language proficiency* did not significantly moderate the effect between preservice teachers' $pPCK_{post}$ and ePCK ($\Delta R^2 = 5.56\%$, $F(1,19) = 0.40$, $p = 0.53$) (Table 3). Whether the noticing of relevant events regarding students' language proficiency would work as a filter between pPCK and ePCK was not supported by our data. Following recommendations by Hayes [73], the interaction term was dropped from Model 2a, resulting in a new simple effects model: 2a *. This new Model 2a * revealed neither a significant relationship between preservice teachers' $pPCK_{post}$ ($\beta = -0{,}02$, $p = 0{,}95$), nor their noticing ($\beta = -0{,}07$, $p = 0{,}76$) for their ePCK.

In Model 2b, we investigated whether the interaction between the preservice teachers' $pPCK_{post}$ and their knowledge-based reasoning about relevant events regarding students' language proficiency predicted their ePCK. This Model 2b was significant ($F(3,19) = 10.40$, $p < 0.001$), predicting 25.72% of the variance, meaning that, according to Cohen [74], a large amount of the variance in ePCK could be explained by these predictors. An analysis showed that *knowledge-based reasoning about relevant events regarding students' language proficiency* significantly moderated the effect between the preservice teachers' $pPCK_{post}$ and ePCK ($\Delta R^2 = 12.95\%$, $F(1,19) = 12.53$, $p < 0.01$) (Table 3). This analysis supports the hypothesis that knowledge-based reasoning about relevant events regarding students' language proficiency works as a filter between pPCK and ePCK.

To explore the direction of the moderation effect, a Johnson–Neyman plot was made (Figure 6). It showed that the conditional effect of pPCK on ePCK is significant ($p < 0.05$) if the moderator variable *knowledge-based reasoning* is outside the interval [51.13, 51.55]. Higher values of *knowledge-based reasoning* led to a positive conditional effect of pPCK on ePCK, whereas lower values led to a negative conditional effect of pPCK on ePCK.

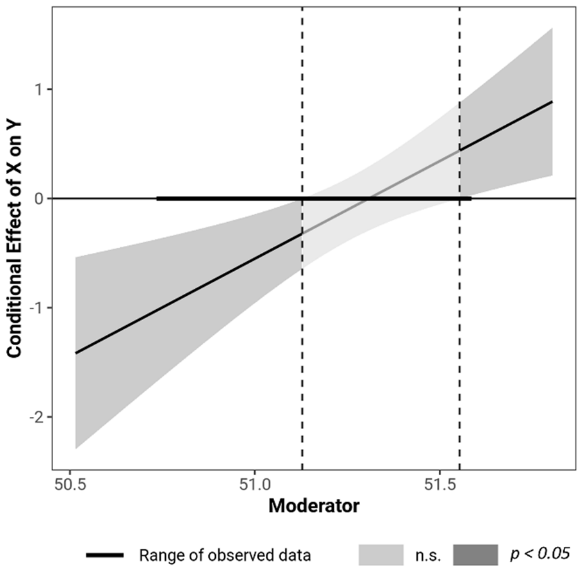

Figure 6. Johnson–Neyman plot to illustrate the direction of the moderation effect of knowledge-based reasoning. If the moderator variable *knowledge-based reasoning* is outside the interval [51.13, 51.55], then the conditional effect of pPCK on ePCK is significant ($p < 0.05$).

5. Discussion and Implications

The results of our study indicate that imparting cPCK in the framework of a seminar fosters preservice biology teachers' development of pPCK. Furthermore, preservice biology teachers' knowledge-based reasoning moderates the transformation process between pPCK and ePCK, and therefore can be defined as a filter (Figure 7).

We further hypothesised that *motivational orientations* and *professional values* would moderate the transformation process between cPCK and pPCK: teachers' motivational orientations and professional values should play a decisive role in their (subconscious) decisions on which parts of cPCK they integrate into their pPCK [8,10,11,17]. With our data, we could not support these hypotheses. Although there is little research about teachers' professional values [12], we assumed and found a strong correlation between teachers' professional values and their motivational orientations, as they are both affective components of teachers' competence. Both our moderation models were significant, predicting more than 40% of the variance. Further calculations showed that it was actually the preservice teachers' $pPCK_{pre}$ that significantly predicted their $pPCK_{post}$. Because the value for motivational orientations was very close to the edge of significance, we recommend further research.

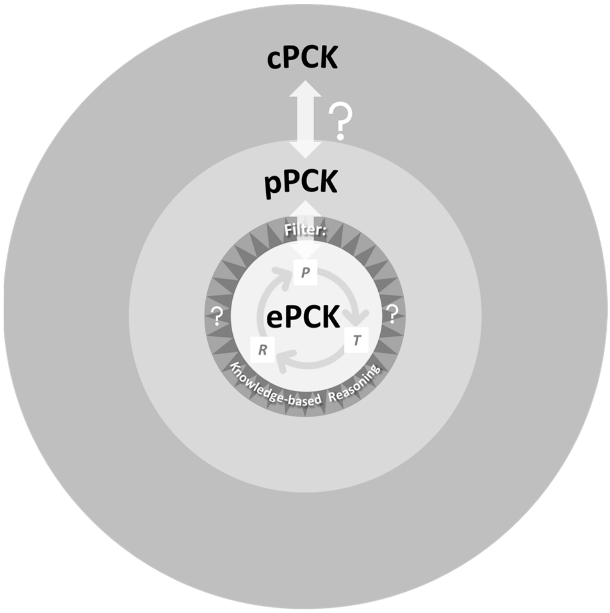

Figure 7. Knowledge-based reasoning as a filter between pPCK and ePCK.

Kunter et al. [75] successfully measured teachers' professional knowledge, but they did not distinguish the realms of PCK. Carlson and Daehler [1] did distinguish them, but they did not propose a way to measure them. Because we cannot measure a person's cPCK, we decided to measure the preservice teachers' pPCK at the beginning of the semester, when they did not possess that much. By measuring their pPCK at the end of the semester, we interpreted the increase in pPCK as the parts of cPCK taught in the lectures that they integrated into their pPCK.

To follow, as far as possible, the assumption that ePCK only occurs in the concrete teaching situation [6], we decided to focus on the planning aspect of ePCK to measure the preservice teachers' ePCK. Usually, teachers plan their lessons in writing. Therefore, written lesson plans should map their $ePCK_P$. We are aware that this will only be an approach to the core of cPCK, or ePCK, and will raise further questions: Is pPCK a subset of cPCK, and ePCK a subset of pPCK, as suggested by Carlson and Daehler [1]? Did we measure an intersection between cPCK and pPCK, or between pPCK and ePCK?

Furthermore, we hypothesised that the *noticing of* and *knowledge-based reasoning about relevant events regarding students' language proficiency* would moderate the transformation process between pPCK and ePCK. In our study, the moderation model with noticing as a moderator variable was not significant, and noticing did not moderate the transformation process from pPCK to ePCK. Our moderation model with the moderator variable knowledge-based reasoning was significant, and knowledge-based reasoning moderates the transformation process between pPCK and ePCK, which supports Carlson and Daehler's [1] assumption about teachers' pedagogical reasoning working as a filter between these two realms. Therefore, our results indicate that, from a certain level, the better the preservice teachers' knowledge-based reasoning, the stronger the effect on the transformation process from pPCK to ePCK. Furthermore, from a further certain level, this effect turns negative: the worse preservice teachers' knowledge-based reasoning, the smaller the transformation from pPCK to ePCK. Because the person-reliability scores for noticing and knowledge-based reasoning were on the low end, the test instrument was only able to distinguish two groups of preservice teachers: those with high and those with low knowledge-based reasoning. Being able to distinguish more than two groups would provide more insights into a possible moderation of the transformation from pPCK to ePCK. Therefore, our first results should be treated with care, and especially because we did not find a moderation effect of noticing on this transformation, which could be due to the rather low reliability of the used test. According to Seidel and Stürmer [23], the noting of relevant classroom events is a prerequisite for subsequent knowledge-based reasoning, which has to be used for making decisions about teaching strategies expressed as ePCK. Processing the experiences of each unique teaching situation feeds into a teacher's pPCK [1]. Following the model of professional vision [23], we assumed and found a strong correlation between teachers' noticing and knowledge-based reasoning. To investigate the relations between the variables in more detail, we suggest conducting a path analysis with a larger sample size. However, being aware of the limitations of our study, we recommend strongly, on the basis of our results, the fostering of preservice teachers' knowledge-based reasoning, together with their PCK, as PCK can be activated, or even increased, through the confrontation with classroom situations and by going through a structured knowledge-based-reasoning process [76–78]. Training the three steps of knowledge-based-reasoning description, explanation [23,25], and the proposing of alternative instructional strategies [26,27] can increase preservice teachers' PCK [79]. Our results indicate that ePCK, in particular, can be increased, and even decreased, if preservice teachers' knowledge-based reasoning is on a low level.

As research findings support the importance of language proficiency for students' performance in science [4], and there are insights into the specifics of language in science education and appropriate instructional strategies [16,30,35,42,71,80], cPCK in the field of language in science education is therefore available. To transform this cPCK into every science teacher's pPCK, and from there to ePCK, would be in all students' interests. Therefore, further filters and amplifiers that moderate these transformation processes should be identified.

The results of our study provide the first evidence for the hypothesised filters between the realms of PCK. Further research is recommended for the other and further filters, as well as for other content sections of PCK. We strongly recommend further research in the field of motivational orientations and professional values, as there is a research gap in the area of affective factors, and we assume them to be decisive, but not yet clarified, impact factors. We feel it is necessary to examine the suggested filters between the realms of PCK in greater depth with a larger sample size, and by using a mixed-methods approach. Teachers' $ePCK_T$ and $ePCK_R$ should be focussed as well by recording the lessons and articulated reflection process after the lessons. Both would have to be coded using the same criteria as the written lesson plans, which we used to analyse $ePCK_P$. Knowing that teaching is extremely complex and challenging, we suggest considering the investigation of further filters in the transformation process between the realms of PCK, such as a teacher's epistemological beliefs, content knowledge, pedagogical/psychological knowledge, and aspects of the learning context, as described by Carlson and Daehler [1].

We are aware of the limitations of our study: First, all the test instruments had to be adapted or developed within the context of the study, as there were no existing ones. We carefully considered the content and construct validity, as described above. Because the findings about knowledge-based reasoning as a filter between the transformation process from pPCK to ePCK depend on the used test instruments, their validation should be supplemented by a further category of evidence [58].

Second, in contrast to the RCM, we did not investigate in-service teachers' PCK, but preservice teachers' PCK in the framework of their teacher-education programme. During the intervention in the biology class at school, we were not able to provide the feeling of full responsibility for the class: the preservice teachers were alone in the classroom during the teaching situation, as the lessons were broadcasted live to the observation room, but they were not responsible for the students' learning and the grading by the students, parents, or the headmaster. They had to acquire ECTS credits by attending the seminar, providing written lesson plans, and joining the teaching and reflection situations, which could have influenced their motivational orientations, although neither their performance in class and joint reflection, nor the quality of their written lesson plans, led to any kind of grade. Surprisingly, the preservice teachers' motivational orientations correlated negatively with their $ePCK_P$. One possible explanation could be that those preservice teachers who have high motivational orientations to implement language-sensitive biology instruction have not yet realised the importance of sound written lesson planning, and therefore did not put that much effort in writing good lesson plans. Due to these limitations, we recommend the implementation of further research with in-service teachers based on our findings.

Becoming acquainted with the decisive filters between the realms of PCK, of which our study provides the first insights, is a prerequisite for interventions from which teachers and students will benefit: we need excellent teachers to give young people the best educational opportunities, and it is science-education research's task to support science-teacher education. The findings of our study will enable us to improve our biology-teacher education programme on the one hand, and to explore further filters on the other.

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References

1. Carlson, J.; Daehler, K.R. The Refined Concensus Model of Pedagogical Content Knowledge in Science Education. In *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science*; Hume, A., Cooper, R., Boroswki, A., Eds.; Springer: Singapore, 2019; pp. 77–92.
2. Berry, A.; Friedrichsen, P.; Loughran, J. (Eds.) *Re-Examining Pedagogical Content Knowledge in Science Education*; Routledge: New York, NY, USA; London, UK, 2015.
3. Shulman, L.S. Those Who Understand: Knowledge Growth in Teaching. *Educ. Res.* **1986**, *15*, 4–14. [CrossRef]
4. Prediger, S.; Wilhelm, N.; Büchter, A.; Gürsoy, E.; Benholz, C. Sprachkompetenz und Mathematikleistung—Empirische Untersuchung sprachlich bedingter Hürden in den Zentralen Prüfungen 10. *Journal für Mathematik Didaktik* **2015**, *36*, 77–104. [CrossRef]
5. Baumert, J.; Kunter, M. Das Kompetenzmodell von COACTI. In *Professionelle Kompetenz von Lehrkräften*; Kunter, M., Baumert, J., Blum, W., Klusmann, U., Krauss, S., Neubrand, M., Eds.; Waxmann: Münster, Germany, 2011; pp. 29–54.
6. Alonzo, A.C.; Berry, A.; Nilsson, P. Unpacking the Complexity of Science Teachers' PCK in Action: Enacted and Personal PCK. In *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science*; Hume, A., Cooper, R., Boroswki, A., Eds.; Springer: Singapore, 2019; pp. 271–286.
7. Woolfolk Hoy, A.; Davis, H.; Pape, S.J. Teacher Knowledge and Beliefs. In *Handbook of Educational Psychology*; Alexander, P.A., Winne, P.H., Eds.; Routledge: New York, NY, USA, 2006; pp. 715–737.
8. Kunter, M. Motivation als Teil der professionellen Kompetenz—Forschungsbefunde zum Enthusiasmus von Lehrkräften. In *Professionelle Kompetenz von Lehrkräften*; Kunter, M., Baumert, J., Blum, W., Klusmann, U., Krauss, S., Neubrand, M., Eds.; Waxmann: Münster, Germany, 2011; pp. 259–275.
9. Oser, F. Wann lernen Lehrer ihr Berufsethos? In *Die Institutionalisierung von Lehren und Lernen*; Leschinsky, A., Ed.; Beltz: Weinheim, Germany, 1996; pp. 235–243.
10. Wigfield, A.; Eccles, J.S. Expectancy-Value Theory of Achievement Motivation. *Contemp. Educ. Psychol.* **2000**, *25*, 68–81. [CrossRef] [PubMed]
11. Mitchell, T.R. Matching Motivational Strategies with Organizational Contexts. *Res. Organ. Behav.* **1997**, *19*, 57–149.
12. Baumert, J.; Kunter, M. Stichwort: Professionelle Kompetenz von Lehrkräften. *ZfE* **2006**, *9*, 469–520. [CrossRef]
13. Gollan, T. Sozialer Einfluss auf Werthaltungen und seine Konsequenzen für kulturelle Diffusion. Ph.D. Thesis, Universität Hamburg, Hamburg, Germany, 2012.

14. Mecheril, P.; Quehl, T. Die Sprache der Schule. Eine migrationspädagogische Kritik der Bildungssprache. In *Sprache und Bildung in Migrationsgesellschaften: Machtkritische Perspektiven auf ein prekarisiertes Verhältnis*; Thoma, N., Knappig, M., Eds.; Transcript: Bielefeld, Germany, 2015; pp. 151–177.
15. Schmidt, B. *Den Anti-Bias-Ansatz zur Diskussion stellen. Beitrag zur Klärung theoretischer Grundlagen in der Anti-Bias-Arbeit*; BIS-Verlag der Carl von Ossietzky Universität: Oldenburg, Germany, 2009.
16. Tajmel, T.; Hägi-Mead, S. *Sprachbewusste Unterrichtsplanung. Prinzipien, Methoden und Beispiele für die Umsetzung*; Waxmann: Münster, Germany; New York, NY, USA, 2017.
17. Bardi, A.; Goodwin, R. The Dual Route to Value Change: Individual Processes and Cultural Moderators. *J. Cross Cult. Psychol.* **2011**, *42*, 271–287. [CrossRef]
18. Calogero, R.M.; Bardi, A.; Sutton, R.M. A need basis for values: Associations between the need for cognitive closure and value priorities. *Pers. Individ. Differ.* **2009**, *46*, 154–159. [CrossRef]
19. Meschede, N.; Fiebranz, A.; Möller, K.; Steffensky, M. Teachers' Professional Vision, Pedagogical Content Knowledge and Beliefs: On its Relation and Differences Between Pre-Service and In-Service Teachers. *Teach. Teach. Educ.* **2017**, *66*, 158–170. [CrossRef]
20. Sherin, M.G. Developing a Professional Vision of Classroom Events. In *Beyond Classical Pedagogy. Teaching Elementary School Mathematics*; Wood, T.L., Nelson, B.S., Warfield, J., Eds.; Routledge: New York, NY, USA, 2001; pp. 75–93.
21. Sherin, M.G. The Development of Teachers' Professional Vision in Video Clubs. In *Video Research in the Learning Sciences*; Goldman, R., Ed.; Erlbaum: Mahwah, NJ, USA, 2007; pp. 383–395.
22. Stürmer, K.; Seidel, T. Assessing Professional Vision in Teacher Candidates. *Zeitschrift für Psychologie* **2015**, *223*, 54–63. [CrossRef]
23. Seidel, T.; Stürmer, K. Modeling and Measuring the Structure of Professional Vision in Preservice Teachers. *Am. Educ. Res. J.* **2014**, *51*, 739–771. [CrossRef]
24. Borko, H. Professional Development and Teacher Learning: Mapping the Terrain. *Educ. Res.* **2004**, *33*, 3–15. [CrossRef]
25. Van Es, E.A.; Sherin, M.G. Learning to Notice: Scaffolding New Teachers' Interpretations of Classroom Interactions. *J. Technol. Teach. Educ.* **2002**, *10*, 571–596.
26. Santagata, R.; Yeh, C. The Role of Perception, Interpretation, and Decision Making in the Development of Beginning Teachers' Competence. *ZDM Math. Educ.* **2016**, *48*, 153–165. [CrossRef]
27. Blömeke, S.; Gustafsson, J.-E.; Shavelson, R.J. Beyond Dichotomies. *Zeitschrift für Psychologie* **2015**, *223*, 3–13. [CrossRef]
28. Moschkovich, J.N. Academic Literacy in Mathematics for English Learners. *J. Math. Behav.* **2015**, *40*, 43–62. [CrossRef]
29. Halliday, M.A.K. *Learning How to Mean. Explorations in the Development of Language*; Arnold: London, UK, 1975.
30. Childs, P.E.; Markic, S.; Ryan, M.C. The Role of Language in the Teaching and Learning of Chemistry. In *Chemistry Education. Best Practices, Opportunities and Trends*; Garcia-Martinez, J., Serrano-Torregrosa, E., Eds.; Wiley-VCH: Weinheim, Germany, 2015; pp. 421–446.
31. Riebling, L. Heuristik der Bildungssprache. In *Herausforderung Bildungssprache—Und wie man sie meistert*; Gogolin, I., Lange, I., Michel, U., Reich, H.H., Eds.; Waxmann: Münster, Germany, 2013; pp. 106–153.
32. Nitz, S.; Nerdel, C.; Prechtl, H. Entwicklung eines Erhebungsinstruments zur Erfassung der Verwendung von Fachsprache im Biologieunterricht. *ZfDN* **2012**, *18*, 117–139.
33. Taber, K.S. Exploring the Language(s) of Chemistry Education. *Chem. Educ. Res. Pract.* **2015**, *16*, 193–197. [CrossRef]
34. Behling, F.; Förtsch, C.; Neuhaus, B.J. Sprachsensibler Biologieunterricht—Förderung professioneller Handlungskompetenz und professioneller Wahrnehmung durch videogestützte live-Unterrichtsbeobachtung. Eine Projektbeschreibung. *ZfDN* **2019**, *25*, 307–316. [CrossRef]
35. Drumm, S. *Sprachbildung im Biologieunterricht*; De Gruyter Mouton: Berlin, Germany, 2016.
36. Nitz, S.; Enzingmüller, C.; Prechtl, H.; Nerdel, C. Fachsprache im naturwissenschaftlichen Unterricht—Eine empirische Untersuchung zur Einstellung angehender Lehrkräfte. *Unterrichtswissenschaft* **2011**, *39*, 245–262.
37. Retzlaff-Fürst, C. Protokollieren, Zeichnen und Mathematisieren. In *Fachdidaktik Biologie*; Gropengießer, H., Harms, U., Kattmann, U., Eds.; Aulis: Seelze, Germany, 2016; pp. 312–324.
38. Kotzebue, L. von. Diagrammkompetenz als biologiedidaktische Aufgabe für die Lehrerbildung: Konzeption, Entwicklung und empirische Validierung eines Strukturmodells zum diagrammspezifischen Professionswissen im biologischen Kontext. Ph.D. Thesis, Technische Universität München, München, Germany, 2014.
39. Mecheril, P.; Castro Varela, M.d.M.; Dirim, İ.; Kalpaka, A.; Melter, C. *Migrationspädagogik*; Beltz: Weinheim, Germany; Basel, Switzerland, 2010.
40. Moore, F.M. Language in Science Education as a Gatekeeper to Learning, Teaching, and Professional Development. *J. Sci. Teach. Educ.* **2007**, *18*, 319–343. [CrossRef]
41. Prediger, S. Sprachbildung im Fachunterricht, ja klar, aber was genau, und wie? Überblicke und Einblicke in mathematikspezifische empirische Studien. In *Fachgespräch*; Ludwig-Maximilians-Universität: München, Germany, 2017.
42. Markic, S. Chemistry Teachers' Pedagogical Scientific Language Knowledge. In *Research, Practice and Collaboration in Science Education. Proceedings of ESERA 2017*; Finlayson, O.E., McLoughlin, E., Erduran, S., Childs, P., Eds.; Dublin City University: Dublin, Ireland, 2018; pp. 178–185.
43. Bunch, G.C. Pedagogical Language Knowledge. *Rev. Res. Educ.* **2013**, *37*, 298–341. [CrossRef]
44. Tajmel, T. *Naturwissenschaftliche Bildung in der Migrationsgesellschaft: Grundzüge einer Reflexiven Physikdidaktik und kritisch-sprachbewussten Praxis*; Springer: Berlin, Germany, 2017.

45. Eccles, J.S.; Adler, T.F.; Futterman, R.; Goff, S.B.; Kaczala, C.M.; Meece, J.L.; Midgley, C. Expectancies, Values, and Academic Behaviors. In *Achievement and Achievement Motives. Psychological and Sociological Approaches*; Spence, J.T., Ed.; W.H. Freeman: San Francisco, CA, USA, 1983; pp. 75–146.
46. Förtsch, C.; Sczudlek, M.; Neuhaus, B.J. Kompetenzorientierung und Aufgabenkultur im Natur-und-Technik-Unterricht. Eine Videostudie. In *Erkenntnisweg Biologiedidaktik 12*; Krüger, D., Schmiemann, P., Möller, A., Dittmer, A., Zabel, J., Eds.; Universitätsdruckerei: Kassel, Germany, 2013; pp. 75–88.
47. Boone, W.J.; Staver, J.R.; Yale, M.S. *Rasch Analysis in the Human Sciences*; Springer: Dordrecht, The Netherlands, 2014.
48. Linacre, J.M. USCALE = The User-Scaled Value of 1 Logit = 1. Available online: https://winsteps.com/winman/uscale.htm (accessed on 13 July 2022).
49. Linacre, J.M. What do Infit and Outfit, Mean-Square and Standardized Mean? *RMT* **2002**, *16*, 878.
50. Wright, B.D.; Linacre, J.M. Reasonable Mean-Square Fit Values. *RMT* **1994**, *8*, 370.
51. Boone, W.J.; Noltemeyer, A. Rasch Analysis: A Primer for School Psychology Researchers and Practitioners. *Cogent. Educ.* **2017**, *4*, 1416898. [CrossRef]
52. Linacre, J.M. User's Guide to Winsteps®Ministeps Rasch-Model Computer Programs. Program Manual 5.2.4. Available online: https://www.winsteps.com/a/Winsteps-Manual.pdf (accessed on 13 July 2022).
53. Behling, F.; Förtsch, C.; Neuhaus, B.J. Using the Plan-Teach-Reflect Cycle of the Refined Consensus Model of PCK to Improve Pre-Service Biology Teachers' Personal PCK as Well as Their Motivational Orientations. *Educ. Sci.* 2022, *submitted*.
54. Jüttner, M.; Boone, W.; Park, S.; Neuhaus, B.J. Development and Use of a Test Instrument to Measure Biology Teachers' Content Knowledge (CK) and Pedagogical Content Knowledge (PCK). *Educ. Assess. Eval. Account.* **2013**, *25*, 45–67. [CrossRef]
55. Schmelzing, S.; van Driel, J.H.; Jüttner, M.; Brandenbusch, S.; Sandmann, A.; Neuhaus, B.J. Development, Evaluation, and Validation of a Paper-and-Pencil Test for Measuring Two Components of Biology Teachers' Pedagogical Content Knowledge Concerning the "Cardiovascular System". *Int. J. Sci. Math Educ.* **2013**, *11*, 1369–1390. [CrossRef]
56. Jüttner, M.; Neuhaus, B.J. Das Professionswissen von Biologielehrkräften—Ein Vergleich zwischen Biologielehrkräften, Biologen und Pädagogen. *ZfDN* **2013**, *19*, 31–49.
57. Jüttner, M.; Neuhaus, B.J. Validation of a Paper-and-Pencil Test Instrument Measuring Biology Teachers' Pedagogical Content Knowledge by Using Think-Aloud Interviews. *J. Educ. Train Stud.* **2013**, *1*, 113–125. [CrossRef]
58. Reeves, T.D.; Marbach-Ad, G. Contemporary Test Validity in Theory and Practice: A Primer for Discipline-Based Education Researchers. *CBE Life Sci. Educ.* **2016**, *15*. [CrossRef]
59. Wiggins, G.P.; McTighe, J. *Understanding by Design*; Association for Supervision and Curriculum Development: Alexandria, VA, USA, 2005.
60. Boone, W.; Rogan, J. Rigour in Quantitative Analysis: The Promise of Rasch Analysis Techniques. *Afr. J. Res. Math. Sci. Technol. Educ.* **2005**, *9*, 25–38. [CrossRef]
61. Aryadoust, S.V. Mapping Rasch-Based Measurement onto the Argument-Based Validity Framework. *Rasch Meas. Trans.* **2009**, *23*, 1192–1193.
62. Planinic, M.; Boone, W.J.; Susac, A.; Ivanjek, L. Rasch Analysis in Physics Education Research: Why Measurement Matters. *Phys. Rev. Phys. Educ. Res.* **2019**, *15*, 020111. [CrossRef]
63. Mecheril, P.; Quehl, T. Sprache und Macht. Theoretische Facetten eines (migrations-)pädagogischen Zusammenhangs. In *Die Macht der Sprachen. Englische Perspektiven auf die mehrsprachige Schule*; Mecheril, P., Quehl, T., Eds.; Waxmann: Münster, Germany, 2006; pp. 355–381.
64. Behling, F.; Förtsch, C.; Neuhaus, B.J. Biologieunterricht bewerten I: Vorstellung eines theoriebasierten Bewertungsbogens zur Qualitätseinschätzung von Artikulationsschemata. *MNU J.* **2021**, *74*, 508–512.
65. Schröder, J.; Riese, J.; Vogelsang, C.; Borowski, A.; Buschhüter, D.; Enkrott, P.; Kempin, M.; Kulgemeyer, C.; Reinhold, P.; Schecker, H. Die Messung der Fähigkeit zur Unterrichtsplanung im Fach Physik mit Hilfe eines standardisierten Performanztests. *ZfDN* **2020**, *26*, 103–122. [CrossRef]
66. Tajmel, T. *Sprachliche Lernziele des naturwissenschaftlichen Unterrichts*; Stiftung Mercator; Universität Duisburg-Essen: Duisburg, Germany, 2011. Available online: https://www.uni-due.de/imperia/md/content/prodaz/sprachliche_lernziele_tajmel.pdf (accessed on 13 July 2022).
67. Gogolin, I.; Lange, I. Bildungssprache und durchgängige Sprachbildung. In *Migration und schulischer Wandel: Mehrsprachigkeit*; Fürstenau, S., Gomolla, M., Eds.; VS Verlag für Sozialwissenschaften: Wiesbaden, Germany, 2011; pp. 107–127.
68. Dorfner, T.; Förtsch, C.; Neuhaus, B.J. Use of Technical Terms in German Biology Lessons and Its Effects on Students' Conceptual Learning. *Res. Sci. Technol. Educ.* **2020**, *38*, 227–251. [CrossRef]
69. Özayli, G.; Ortner, R. Wie über sich selbst nachdenken? Machtkritische Reflexionsperspektiven für Pädagog_innen im Kontext von Mehrsprachigkeit. In *Sprache und Bildung in Migrationsgesellschaften: Machtkritische Perspektiven auf ein prekarisiertes Verhältnis*; Thoma, N., Knappig, M., Eds.; Transcript: Bielefeld, Germany, 2015; pp. 205–219.
70. Sandmann, A.; Schmiemann, P.; Neuhaus, B.J.; Tiemann, R. Fachdidaktische Strukturierung als Qualitätsmerkmal naturwissenschaftlichen Unterrichts: Sachstrukturen und Vernetzung, Kontext- und Aufgabenorientierung. In *nwu-essen. 10 Jahre Essener Forschung zum naturwissenschaftlichen Unterricht*; Fischer, H.E., Sumfleth, E., Eds.; Logos: Berlin, Germany, 2013; pp. 121–162.
71. Beese, M.; Kleinpaß, A.; Krämer, S.; Reschke, M.; Rzeha, S.; Wiethoff, M. *Praxishandbuch Sprachbildung in Biologie. Sprachsensibel unterrichten—Sprache fördern*; Klett: Stuttgart, Germany, 2015.

72. Gogolin, I. Chancen und Risiken nach PISA—Über Bildungsbeteiligung von Migrantenkindern und Reformvorschläge. In *Schieflagen im Bildungssystem. Die Benachteiligung der Migrantenkinder*; Auernheimer, G., Ed.; Springer Fachmedien: Wiesbaden, Germany, 2013; pp. 33–50.
73. Hayes, A.F. *Introduction to Mediation, Moderation, and Conditional Process Analysis. A Regression-Based Approach*; The Guilford Press: New York, NY, USA; London, UK, 2018.
74. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*; L. Erlbaum Associates: Hillsdale, MI, USA, 1988.
75. Kunter, M.; Baumert, J.; Blum, W.; Klusmann, U.; Krauss, S.; Neubrand, M. (Eds.) *Professionelle Kompetenz von Lehrkräften*; Waxmann: Münster, Germany, 2011.
76. Stürmer, K.; Könings, K.D.; Seidel, T. Declarative Knowledge and Professional Vision in Teacher Education: Effect of Courses in Teaching and Learning. *Br. J. Educ. Psychol.* **2013**, *83*, 467–483. [CrossRef]
77. Santagata, R.; Guarino, J. Using Video to Teach Future Teachers to Learn from Teaching. *ZDM Math. Educ.* **2011**, *43*, 133–145. [CrossRef]
78. Kersting, N.B.; Givvin, K.B.; Thompson, B.J.; Santagata, R.; Stigler, J.W. Measuring Usable Knowledge. *Am. Educ. Res. J.* **2012**, *49*, 568–589. [CrossRef]
79. Kramer, M.; Förtsch, C.; Boone, W.J.; Seidel, T.; Neuhaus, B.J. Investigating Pre-Service Biology Teachers' Diagnostic Competences: Relationships between Professional Knowledge, Diagnostic Activities, and Diagnostic Accuracy. *Educ. Sci.* **2021**, *11*, 89. [CrossRef]
80. Tajmel, T.; Starl, K.; Schön, L.-H. Detect the Barriers and Leave Them Behind—Science Education in Culturally and Linguistically Diverse Classrooms. In *Science Education Unlimited: Approaches to Equal Opportunities in Learning Science*; Tajmel, T., Starl, K., Eds.; Waxmann: Münster, Germany, 2009; pp. 67–84.